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(54) IMPROVEMENTS IN FLOATING, DEEP-DIGGING LADDER-TYPE DREDGES

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This invention relates to improvements in floating, deep-digging ladder-type dredges.

While ladder dredges have been used for many years in excavating subaqueous materials for marine construction work and, to some extent for mining minerals, they have heretofore been confined to relatively shallow depths and to relatively quiet water.

In operations where the water is not a quiet pond, particularly with offshort dredges operating in the ocean, swells and waves cannot be avoided. The result has been that dredges could operate offshore only during times when the water was very quiet, and they had to remain idle much of the time. Even then, each time as well or wave would rise, the excavating means, such as a cutter head or other digging device, operative at the lower end of the ladder, would be lifted from engagement with the sand, soil or rock, and so a large proportion of the time very little material would be dug. The alternative to this would have damaged the excavating means, the ladder, and related structural and mechanical components by having the lower ladder end and the excavating means repeatedly strike the material being dug with great force as each wave or swell subsided. These same conditions restricted the offshore operations to relatively shallow protected water, even though it was often desirable to economically excavate subaqueous materials or minerals that lay more than sixty feet below the surface of the ocean in exposed water which might be fairly close to shore.

According to the invention, there is provided a floating deep-dipping dredge having a hull, a dredge ladder pivotally supported by the hull for relative swinging movement in a vertical plane only, and excavating means operative at the lower end of the ladder, such dredge including block-and-tackle suspension means for the ladder supported by superstructure on the hull and connected to the lower end of at least one swingable ladder section for support thereof, winch means for a cable of the block-and-tackle suspension means, sounding means for determining instantaneously the height of the hull above the bottom of the water on which the hull is floating, depth signal generating means actuated by the sounding means, angle sensing means for determining instantaneously the angle which the true horizontal makes with the nominally horizontal centre line of the hull, angle signal generating means actuated by the angle sensing means, and control means receiving the depth signal and the angle signal and controlling the length of the suspension means to accommodate the ladder to swells in the water level on which the hull floats.

In a preferred embodiment, the dredge further includes a stern line and two quarter lines for extending from respective sea bottom anchors to the dredge, a stern line winch and two quarter line winches for varying the length of the stern line and quarter lines, and means actuated by the control means for controlling the instantaneous length of the stern line and quarter lines during swells.

In offshore dredges embodying the present invention compensation can be made so that the dipping engagement of the dredge excavating means, well below the surface, is substantially unaffected by swell and wave conditions. This does not mean, of course, that dredging should be carried on when the seas become rough, but in other than rough or stormy conditions, an ocean-going dredge embodying this invention can operate efficiently even with relatively high swells and

even where the minerals or other materials lie well below the surface of the sea.

In order that the invention may be readily understood, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a simplified view of a side elevation of an offshort dredge embodying the principles of the invention and having an articulated ladder made in two sections. In this view the two ladder sections are aligned in a straight line. Broken lines show a higher digging position of the cutter head and the lower ladder end.

Figure 2 is a view similar to Figure 1 of the dredge of Figure 1 in a position where the lower section is inclined downwardly relative to the upper section, in order to compensate for a swell. Broken lines show the relative positions of the ladder sections at the trough of the swell.

Figure 3 is a plan view of the dredge of Figure 2, showing the dredge-positioning and swinging lines.

Figure 4 is a simplified view in side elevation of a modified form of a deep digging dredge also embodying the principles of this invention, made in four articulated ladder sections. The four ladder sections are aligned in a straight line, with broken centre lines showing the relative positions of the ladder sections under swell conditions. Other positions of the ladder sections, at greater digging depths, under swell conditions are also shown by broken lines.

Figure 5 is a motion diagram of an off-shore dredge like those of Figures 1 to 4 compensated for swell conditions. This motion diagram shows the vertical and horizontal compensating components and the resultant required to provide for swell.

Figure 6 is an enlarged view in side elevation and in section of an articulated ladder section, broken twice in the middle, also showing the cutter head with drive, the pump suction pipe with flexible connections, and the main pump with drive located in the dredge hull.

Figure 7 is a fragmentary plan view of a portion of the ladder of Figure 6 at the articulated pivot connection.

Figure 8 is a view in side elevation, partly in section of a modified form of lower ladder section end, showing the optional use, in lieu of a cutter head, of a hydraulic venturi jet system for digging and recovering subaqueous materials.

Figure 9 is a view in side elevation and in section of another modified form of lower ladder section end showing the optional use of a bucket wheel device for excavating and recovering subaqueous materials.

Figure 10 is a view in front elevation of a dredge skew suspension system for the lowermost articulated ladder section.

Figure 11 is a view in side elevation of the suspension system of Figure 10.

Figure 12 is an enlarged fragmentary view of the connection of the suspension to the lowermost ladder section.

Figure 13 is a fragmentary enlarged view in side elevation of the lower part of the system of Figure 11.

Figure 14 is a diagrammatic view in elevation of the ladder-suspension control apparatus for swell compensation of the dredge of Figure 4.

Figure 15 is a diagrammatic view of the winching system for the dredge of Figure 4.

Figure 16 is a diagrammatic view in side elevation of the ladder and compensating apparatus used in the control of the system of Figure 4.

Figures 17, 18 and 19 comprise an electrical circuit diagram for the device of Figure 4.

Figure 20 is a diagrammatic view in elevation of the input system for the compensation apparatus of Figure 4.

The dredge 150 of Figures 1 to 3, which is designed for deep dredging in offshore or ocean waters where there are swells, has a hull 151 with superstructure 152. The hull 151 supports the uppermost of two articulated ladder sections 153 and 154 by means of a pivot axis member 155 at the top of the upper ladder section 153. The lower ladder section 154 is attached to the lower end of the upper ladder section 153 by a pivot member 156, and it carries a cutter head 159 at its lower end. A single continuous hydraulic pump line 157 is carried by the two ladder sections 153 and 154, running from the cutter head 159 to the suction side of a main pump 158 located in the dredge hull 151. A cutter drive 160 and a booster pump 161 are contained in the ladder sections 154 and 153 respectively.

The cutter head drive 160 and the booster pump 161 can be located within or very close to the suspension points of their respective ladder sections 154 and 153, wherein they are contained; thereby minimising the bending moment in those ladder sections 154 and 153, which is induced by the weight of the cutter head drive 160 and the booster pump 161. This structure is not possible in conventional one-piece ladders, where the booster pump and the drive must be located approximately midway between the upper and lower ends of the one-piece ladder, thereby inducing the maximum bending moment. The location of the pump 161 and drive 160 contributes to enabling reduction in the required section-size and weight of their respective swingable ladder sections.

Each of the articulated ladder sections 153, 154 is adapted to swing pivotally relative to the hull 151 and to its adjacent ladder section. The support and relative swinging may

be accomplished by means of a forward ladder suspension 162 and an after ladder suspension system 163, each of which comprises a block and tackle assembly and a plurality of cables secured at 164 to its ladder. Each of the ladder hoists includes a cable 165 or 166 passing from an upper pulley of the suspension system 162 or 163 to a winch 167 or 168, located at appropriate locations on the hull 151. The forward ladder suspension system 162 is, of course, the longer, since the forward ladder 154 goes down deeper.

A discharge side of the main pump 158 may deliver dredged material to processing equipment aboard the dredge 150, or via a floating pipeline to sites onshore or offshore. Other conventional apparatus for handling the dredge material for mineral recovery or for other purposes may be employed, many such being well known in the dredging art.

In order to enable the ladders 153 and 154 to move up and down from below the hull to above it and back, a suitable well-side slot 169 is provided on the hull 151 to receive the pivot assembly 156 between the ladder sections 153 and 154.

By making the ladder articulated, neither of the ladder sections 153 and 154 has itself to withstand all of the burden; so each ladder section 153 and 154 can be substantially smaller in cross-section and in weight than a one-piece ladder properly designed to do the job. A single ladder capable of dredging down to the depths contemplated in this invention would have to be very heavy and very thick, and it therefore would be quite difficult to raise and lower, as well as being expensive to construct. But by having the ladder in more than one section with an articulated joint between sections and with two suspension assemblies, a much more efficient operation is obtained, enabling far greater depth without correspondingly larger structures.

The dredge of Figures 1 to 3 being for use in offshore or ocean waters where difference between the crests and troughs of a swell may be up to twenty feet or even more, it is apparent that if no attempt is made to compensate for the swell, the cutter head will either not be in continuous engagement with the subaqueous material or will crash into the solid bottom some of the time. In the embodiment of Figures 1 to 3, the dredging face is kept substantially constant, to maintain uniform and continuous digging production and to eliminate cyclical impact forces to the lower ladder end where the digging mechanism is located. The cutter head 159 is kept in a fixed position for any selected digging depth, in relation to the dredging face, and the dredged sea bottom 186 irrespective of the water surface conditions in terms of waves and swells. The cutter head 159 remains at its fixed x , y position (or the x' , y' position shown in broken lines) for any

selected digging depth, while the ladder 153, 154 traverses the cutter head 159 laterally from port to starboard or starboard to port in the process of excavating the subaqueous material. The compensating mechanism includes (1) a sounding device 187 suspended by a cable 188 and (2) an angle indicator 189, which are shown in Figures 2 and 3.

Figures 1 and 2 illustrate the broad effect of the compensating mechanism, which is shown in more detail in Figures 14 to 20. Figure 2 shows the dredge 150 as it is at a swell crest, and Figure 1 shows the same dredge 150 in the swell trough. During the trough time the dredge hull 151 is closed to the bottom 186 than during the crest time; therefore during the crest the lower ladder section 154 is dropped to gain additional depth, as shown in Figure 2, the upper section 153 here remaining unchanged. As the water level drops again to the trough, the ladder is straightened out and may return to the common centre line shown in Figure 1.

Figure 5, a motion diagram, helps to clarify the general aspect of this compensating action by illustrating the vertical movement "a" of the dredge under swell conditions and the compensating resultant "c" required to maintain the cutter head 159 at its fixed x , y position (or x' , y') position for any selected digging depth. This compensation resultant "c" is attained in either direction to compensate for the rise and fall of the hull 151 of the dredge 150. When the hull 151 rises to a swell crest a line 165 pays out to the suspension system 162, enabling the cutter head 159 to remain at the y vertical position, and simultaneously (see Figure 3) quarter lines 174 and 175 are taken up, along with a stern line 173 paying out for the cutter head 159 to remain at the x horizontal position. The reverse action takes place when the dredge hull 151 falls to a swell trough. This resultant movement of the dredge 150 and upper ladder section 153 with respect to the lower ladder section 154 are taken at the ladder pivot connection 156 and are not transmitted to the cutter head 159, which remains at the selected x , y or x' , y' position.

Figures 2 and 3 show a sheave tube 172 or "Christmas tree" containing depression and direction sheaves to lead the stern line 173 and quarter lines 174 and 175 from their respective winches 176, 177 and 178 to anchors on the sea bottom. Bow swing lines 179 and 180 from winches 183 and 184 via sheaves 190, 181 and 191, 182 to sea bottom anchors swing the cutter head 159 with ladder and dredge bow in horizontal arcs about the vertical centre line of the sheave tube 172 to traverse the cutter head 159 from port to starboard and starboard to port in the process of dredging. Other arrangements of positioning and traversing lines well known

to the dredging art may be employed utilizing the principles of this invention for swell compensation.

Figure 3 shows ladder sections 153 and 154 in plan view, with a ladder well slot 169 to provide clearance for the pivot structure 156 when the ladder is raised above the bottom of the hull 151. Ladder hoist winches 167 and 168 are also shown as in Figures 1 and 2 for the respective suspension systems 162 and 163. The engine room 185 of Figure 3 contains the main pump and drive, main engines and auxiliary machinery.

Figure 4 shows a very deep digging dredge 200 for sea or inland waters with four articulated ladder sections 203, 204, 205 and 206, with their respective independent suspension systems 219, 218, 217 and 216, having corresponding ladder hoist winches 227, 226, 225 and 224. This dredge is similar in most respects to dredge 150 of Figures 1 to 3, and for sea dredging can be equipped with a swell compensating system also similar to that of dredge 150. With more than two articulated ladder sections the swell compensating action can be taken at a pivot connection 210 or for swells of greater magnitude at a pivot connection 209. A broken ladder centre line 231 shows the compensating action being taken at the pivot connection 210.

Broken ladder centre line 232 and 233 show the ladder position at a greater digging depth than illustrated by the solid lines. In this case, the compensating action is also taken at the pivot connection 210.

Broken ladder centre lines 234 and 235 show the ladder positions at maximum dipping depth, with swell compensating being taken at the pivot connection 210.

As shown in Figure 20, the sounding device 187, which may be of well-known type acts through cable 188, e.g., in co-operation with pulleys 499 and a weight 500, to provide a mechanical signal indicating the change in the vertical position of the dredge hull 151 up and down as crest and trough conditions occur. This may be interpreted as the height of the hull 151 above the bottom 186 or may be taken from any predetermined point of reference. The mechanical signal from the sounding device 187 is used mechanically to vary the resistance setting of a swell potentiometer 434.

Similarly, the angle indicator 189 is set at or adjacent the pivot member 155 and acts mechanically to vary the resistance setting of a pitch potentiometer 435, in accordance with the angle which the true horizontal makes with the nominally horizontal centre line of the hull 151. The potentiometers 434 and 435 transmit electrical signals as voltages to a swell-and-pitch correction module 491, as shown in Figure 18. The swell-and-pitch correction module 491 operates in co-operation with a Y-co-ordinate command module 492

having a command potentiometer 446 and an X-co-ordinate command module 493 having a command potentiometer 447. The modules 491, 492, and 493 are described below and illustrated in Figure 17.

The cutter head 159 is initially positioned into a preselected x, y (or x', y') position by the Y-coordinate command module 492 and the X-coordinate command module 493; these command modules 492 and 493 are commanded by a winchman manually through the potentiometers 446 and 447. For a dredge 150 like that of Figures 1 and 2, the Y-coordinate command module 492 provides two signals Y1 and Y2, one to set each of the two ladder suspensions 162 and 163, respectively, to move its ladder sections 154 and 153 to the proper elevation. In a dredge like that of Figure 4, there are four such signals because there are four ladder suspensions 216, 217, 218 and 219. In both types of dredge there is only one signal from the X-coordinate command module 493, because that signal controls only a quarter and stern line control module 498.

As the dredge hull 150 begins to rise vertically on an incoming swell from the Figure 1 position to the Figure 2 position, the conventional automatic sounding device indicates the depth of water between the dredged bottom datum 186 and the dredge hull 151. This depth is transmitted by the cable 188 and a swell potentiometer 434 to the swell-and-pitch correction module 491 (Figure 17) to provide correction signals 466 and 465 respectively for the Y' and X' coordinates. A forward ladder suspension control module 494 receives a corrected signal 467 which causes a command signal to be issued that energizes a forward ladder hoist winch motor 400 to run in the lower direction, thus paying out a luffline 165 to the forward ladder suspension 162 by an amount such that the cutter head 159 remains at its desired digging elevation, the y coordinate. Meanwhile, a quarter and stern line control module 498 (Figure 19) receives a corrected signal 471 and issues command signals for quarter lines winch motors 405 and 406 to take up on the quarter lines 174 and 175 and a stern line winch motor 40 to pay out stern line 173 so that the cutter head 159 remains at its x digging coordinate. Thus the x, y position of the cutter head 159 remains the same.

On a falling swell the sounding device 187, the transmitting swell potentiometer 434, and swell-and-pitch correction module 491 provide signals for reverse action of the compensating system, that is, the luffline 162 is taken up and the quarter lines 174 and 175 are paid out and the stern line 173 takes up the required amount.

The swell signal is corrected by a suitable angle measuring device 189 (Figure 20), that measures the variable angle B between the

horizontal centre line of the hull 151 and true horizontal, which, in itself, compensates for fore-and-aft hull trim under sea conditions, further insuring the desired positioning of the cutter head 159 at all times. This angle is transmitted to the swell-and-pitch control module 491 by the potentiometer position indication 435.

Of the command modules 491, 492 and 493 (Figure 17) the X-coordinate command module 493 is the simplest, comprising basically a voltage-to-current converter 439 and a summing amplifier 457, as shown in Figure 17.

The voltage-to-current converter 439 and all the other voltage-to-current converters spoken of in this Specification, may be standard items. For instance, they may each be of a Foxboro 66GT or 66GC series voltage-to-current converter made by the Foxboro Company, of Foxboro, Massachusetts, United States of America. These converters accept a 1 to 5 volt DC input and convert it to a proportional 10 to 50 millampere DC output. A constant current source forming part of this converter excites a remote slide wire, such as the command potentiometer 447. A thousand-ohm slide wire with travel adjusted to approximately 155 to 825 ohms may provide the one-to-five volt DC signal, which is fed to the input of the converter 439. Other values, of course, can be provided. The converter 439 may contain a magnetic and transistor amplifier and be connected to a supply voltage. Since it is a standard item, it need not be further described.

Similarly, the summing amplifier 457 and all the other summing amplifiers used here may be a Foxboro 66CT or 66CC series electronic "Controsol" summing amplifier. These summing amplifiers are able to receive up to four 10 to 50 milliamperes DC input signals and to provide a 10 to 50 milliamperes DC output signal that is proportional to them. The summing amplifier may be a solid-state unit with a two-stage magnetic amplifier connected to a suitable supply voltage. As will be seen, some of the summing amplifiers are used with only two input signals, while others are used with more input signals.

The Y-coordinate command module 492 includes a voltage-to-current converter 438 like the converter 439, which takes its input from the command potentiometer 446 and which supplies, in this instance, two current repeaters 448 and 449. These current repeaters, like the others used in this invention may also be standard items, such as the Foxboro 66BT and 66BC series electronic "Controsol" current repeaters. These repeaters receive a 10 to 50 milliamperes DC input signal and produce an electrically isolated 10 to 50 milliamperes DC output. They have a low input resistance of about 100 ohms and can feed an external load up to 660 ohm. Such units are often

used to extend the total load fed by computer devices to transmitters. They may be of solid-state construction throughout with a magnetic transistor amplifier, and, of course, they have many uses other than in this invention. Each of them is connected to a suitable supply voltage.

The Y-coordinate command module 492 also includes one summing amplifier 456, which is connected to the current repeater 449. This summing amplifier 456 may be a standard unit identical to the summing amplifier 457 already described. The summing amplifier 456 feeds its signal to a signal characterizer 461. Also the current repeater 449 feeds its signal directly to a signal characterizer 462 to produce the Y2 output 468. Each of these signal characterizers 461 and 462, like others to be mentioned later, may be standard items. For example, the Foxboro 66N series signal characterizer, is a completely solid-state instrument that provides up to eight slope adjustments and up to eight break point adjustments for the generation of both linear and nonlinear functions. It includes a buffer amplifier, a shaping circuit, and an operational amplifier, which can be connected in various ways with other minor ingredients.

The swell-and-pitch correction module 391 has two inputs, as already noted, one from the swell command potentiometer 434 operated by the sound device 187, which feeds into a voltage-to-current converter 437, and the other from the pitch command potentiometer module 435 operated by the angle generator 189, which feeds its output to another voltage-to-current converter 436.

The voltage-to-current converter 436 feeds its current output to a current multiplier 452, which is supplied by a constant current source 451. This current multiplier may also be a standard item, such as the Foxboro 66DT and 66DC series electronic "Consotrol" multiplier dividers. These are solid-state analog computing instruments which receive up to three DC input signals at 10 to 50 milliamperes and put out a 10 to 50 milliamperes DC output signal which is proportional to the computed value. There is no electrical isolation between the input, so that only one of the input circuits can be grounded and there should be no external common connections between the input circuits. The constant current source 451 used for this multiplier may be a standard item such as a Foxboro 66ET and 66EC series electronic "Consotrol" current source, which provides an output that is adjustable from 10 to 50 milliamperes. Each may include a transistorised amplifier and other features. Here they are used only for reliable current sources of a standard current to give a fixed multiplier.

The swell-and-pitch correction module 491 also includes two signal characterizers 459 and 460 (like the signal characterizers 461

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and 462). It also includes a summing amplifier 455 and two current multipliers 453 and 454. The current repeater 448 of the Y-coordinate command module 492 is connected to the signal characterizer, 459 and 460 of the swell-and-pitch correction module 491. The current multiplier 452 and the voltage to current converter 437 are connected to the summing amplifier 455. The output from the summing amplifier 455 is connected to the current multipliers 453 and 454. The signal characterizer 459 is also connected to the current multiplier 453, so that the output (or correction signal) 465 from the current multiplier 453 is proportional to the product of the multiplication of the outputs of the signal characterizer 459 and the summing amplifier 455. The summing amplifier 455 and the signal characterizer 460 are connected to a current multiplier 454, whose output or correction signal 466 is proportional to the product of those two inputs.

The current repeater 449 of the Y-coordinate command module 492 is connected to the summing amplifier 456, and the current multiplier 454 feeds its output or correction signal 466 to the summing amplifier 456. The output from the summing amplifier 456 goes to the signal characterizer 461, which thereupon produces the Y1 output 467.

The current repeater 448 feeds its signal to a signal characterizer 459, which feeds its output to the current multiplier 453, and the output from the current multiplier 453 is fed to the summing amplifier 457, which is otherwise fed directly by the voltage-to-current converter 439 of the X-command module 493. This produces the signal output 471 of the X-command module 493.

What has been described so far, then, results in a single output 471 from the X-command module and two outputs 467 and 468 from the Y-coordinate command module, and this concludes the description of Figure 17, for a dredge with two articulated ladder sections.

The output 471 from the X-coordinate command module is fed to the quarter and stern line control module 498. The output 471 is fed directly to a motor operated setter 476 of the control module 498 (Figure 20). This, like the other motor operated setters to be described, may also be a standard item, such as, the M-line, model C, motor operated setter made by Leeds & Northrup Company, of Philadelphia, Pennsylvania, United States of America. This motor-operated setter 476 tracks the signal 471 and positions three retransmitting slide wires which are set-point potentiometers 501, 502 and 503 for respective set-point/auto-manual stations 481, 482 and 483. The set-point potentiometers 501, 502 and 503 are fed directly to their respective set-point/auto-manual stations 481, 482 and 483. This like the other set-point/auto-manual stations to be described,

may also be a standard item such as the Leeds and Northrup Company's M-line, model C, P.A.T., set-point/auto-manual station. The set-point/auto-manual stations 481, 482 and 483 compare the set point potentiometers 501, 502 and 503 with the outputs 508, 509 and 510 of the position feed-back summing amplifiers 443, 444 and 445 (see Figure 19), and the unbalance between the respective signals become respective error signals 515, 516 and 517 that are proportional in magnitude and polarity to the unbalance.

The outputs 515, 516 and 517 are fed directly to the respective position adjusters 488, 489 and 490 (Figure 19). This, like the other position adjusters to be described, may also be a standard item, such as the Leeds and Northrup Company's P.A.T. control known as the M-line Module C control unit. These are used for electric drive units to provide precise control of process variable. They receive an error signal or input (e.g., the error signals 515, 516 and 517 in this instance) from the set point units 481, 482 and 483 and, through an amplifier, energize either a "raise relay" or a "lower relay", depending upon the polarity, magnitude, duration and rate of change of the error signal. They are used in closed loop control systems as the heart of the unit. They are complex units but are well known and are completely described in published material. The signal 471 is used here as the set point, and the position feedbacks are set mechanically through position-feedback potentiometers 410, 411 and 412.

The position-feedback potentiometers 410, 411 and 412 feed their respective signals to the voltage-to-current converters 444, 443 and 445 (like the converter 439). The outputs 508, 509 and 510 from the respective converters 443, 444, and 445 are fed into the set point/auto-manual stations 481, 482 and 483 that provide the error signals 515, 516 and 517 to the position adjusters 488, 489 and 490. The position adjusters 488 and 490 have output cables 522 and 524 each feeding raise-lower control power to the motors 405 and 406 for the quarter line winches 177 and 178. The position adjuster 489 has output cable 523 which feeds raise-lower control power to the motor 404 for the stern line winch. The quarter line position adjusters 488 and 490 are reverse acting in respect to the stern line position adjuster 489. That is, when the stern line position adjuster 489 signals to pay out the stern line, the quarter line position adjusters 488 and 490 will signal for the quarter lines to be taken up. It is obvious that the two quarter lines should be changed the same distance and somewhat less than the stern line.

The output 467 from the Y-coordinate command module 492 is fed to a control module 494. The output 467 is fed directly to a

motor-operated setter 472 (Figure 18), like the motor-operated setter 476. The motor operated setter 472, tracks the signal 467 and positions a retransmitting slide wire set point potentiometer 504 feeding directly to a set point/auto-manual station 477. The set point/auto-manual station 477 compares the set point potentiometer 504, with the output 511 of a summing amplifier 458, and the unbalance between these two signals becomes an error signal 518 that is proportional in magnitude and polarity to the unbalance. The output or error signal 518 is fed directly to a position adjuster 484. The control module 494 also has two position-feedback pressure transmitters 430 and 431 sending signals to a summing amplifier 458 which provides the base signal for the position adjuster 484 from which a raise-lower control output 525 is fed to the forward ladder hoist motor 400 for the winch 167.

The Y-coordinate command module 492 sends its second or Y2 signal 468 to a control module 495. The output 468 is fed directly to a motor operated setter 473, which tracks the signal 468 and positions a retransmitting slide wire set point potentiometer 505, which is fed directly to a set point/auto-manual station 478. The set point/auto-manual station 478 compares the set point potentiometer 505, with the output 512 of a position feedback voltage-to-current converter 440, and the unbalance between these two signals becomes an error signal 519 that is proportional in magnitude and polarity to the unbalance. The output or error signal 519 is fed directly to a position adjuster 485 like those previously described. The signal 468 is used as the set point signal, and the unit's position feedback is controlled by a feedback potentiometer 407, feeding voltage-to-current converter 440. The output 526 from the position adjuster 485 is then used to control the after ladder hoist motor 401 for the winch 168.

As shown in Figures 14, 16 and 18, each of the two ladder suspensions shown in Figure 14 receives a feedback signal that is related to the position of the devices controlled thereby. Thus, the control module 494 for the forward ladder 154 receives feedback from its pressure transmitters 430 and 431 that indicate the depth, the Y-coordinate, of the cutter head. The control module 495 for the after ladder 153 receives the feedback from its potentiometer 407 that indicates the position of the winch drum 168.

The cutter head Y1 coordinate position may be determined by a continuous air-purge system, Figure 16, that provides a continuous signal which is proportional to the vertical distance between the cutter head and the air purge reference 543. The system is a standard liquid level continuous purge type (bubble tube) which consists of two purge systems so arranged that difference in pressure between

the two systems will represent the depth of the cutter head 159 and that this pressure is unaffected by the pitch and/or swell on the hull. Each system may comprise an air filter-regulator 422 and 423, which may be the model 015-025 made by C. A. Norgren Company, of Littleton, Colorado, United States of America, a flow controller 424 and 425 which may be a Brooks Instruments model 8800; and bubble tubes which may comprise pipes 413, 414, 415, 416 and 421; pipe tees 426, pipe plug 427, flexible sections of armoured hose 417, 418, 419 and 420; and electronic pressure transmitters 430 and 431 which may be Foxboro model 611 GM electronic "Consotrol" pressure transmitters; and valves 432. The air filter regulators 422 and 423 supply clean air to the flow controllers 424 and 425. The flow controllers 424 and 425 are set to provide a constant flow of air out the bubble tubes. The pressure at the top of the bubble tubes is transmitted 428 and 429 to the pressure transmitters 430 and 431. This pressure represents the actual static head that the bubble tube is below the water. The pressure transmitters 430 and 431 have force-balance measuring elements and an electronic transmitter which has an output signal 432 or 433 of 10-50 ma D.C. The output signals 432 and 433 are inputs (Figure 18) to the summing amplifier 458 in the control module 494. The output of this summing amplifier 511 is the difference between the two bubble tube pressures, and is the actual distance the cutter head 159 is below the air purge reference 543.

In operation, the command signal for the Y-coordinate command module 492, provided by the potentiometer 446, which is calibrated in feet, is adjusted by the dredge winchman. The slide wire excitation signal built into the voltage-to-current converter 438 provides the excitation for the potentiometer 446, and the output signal of the voltage-to-current converter 438 drives the two current repeaters 448 and 449. The output from the current repeater 448 drives the two signal characterizers 459 and 460 in the swell-and-pitch correction module 491. The output from the current repeater 449 drives the summing amplifier 456 and the signal characterizer 462, whose output signal 468 is the Y2 output 468 used to drive the after ladder suspension control module 495.

The summing amplifier 456 provides the sum of Y plus Y1'. This output drives the signal characterizer 461, which provides the Y1 output signal 467 that drives the forward ladder suspension control modules 494.

The X-coordinate command module 493 input signal is fed to the voltage-to-current converter 439 and from there to the summing amplifier 457, whose other input signal comes from the well-and-pitch correction module 491, and the output 471 therefrom drives the

quarter and stern line control module 498.

The swell-and-pitch correction module 491 receives three signals; the first is from the current repeater 448 of the Y-coordinate command module 492; the second, the pitch from the potentiometer 435 that is positioned by the angle indicator 189; and the third, the swell from the potentiometer 434 which is positioned by the sounding device 187. The pitch signal is proportional to the tangent of angle B, and is sent to a multiplier amplifier 452. The second input to the multiplier amplifier 452 is the constant signal provided by the current source 451, which represents one leg of a triangle. The outputs of the multiplier amplifier 452 is equal to the Y1' pitch components, which is an input to the summing amplifier 455.

The swell signal from the voltage-to-current converter 437 is proportional to the vertical distance that the bottom of the dredge hull 151 lies above the trough of the swell, and this signal is the other input to the summing amplifier 455. The outputs of the summing amplifier 455 is the value of the swell pitch component Y1'. The swell pitch component output of the summing amplifier 455 is corrected according to the depth the dredge is digging by the multiplier amplifier 454, whose second input is from the signal characterizer 460 which is driven by a "Y" coordinate signal. The output 466 of the multiplier amplifier 454 is then equal to the required Y1' coordinate correction, which is input to the Y-coordinate command module 492.

The X' coordinate is computed by the Y1' output from the summing amplifier 455 as one input to the multiplier amplifier 453, and the second input is the output from the signal characterizer 459, which is driven by a Y-coordinate signal. The output 465 of X' coordinate multiplier amplifier 453 is the correction input to the X-coordinate command module 493.

The swell-and-pitch signal may be adjusted and calibrated so that the final output signals 467, 468 and 471 are all positive.

The set point of the position adjuster 484 is adjusted by the input signal 467 from the Y-coordinate command module 492. The set point signal 504 is balanced against the actual feedback signal 511 from the pressure transmitters 431 and 432 and the summing amplifier 458, which represent the actual Y-coordinate of the cutter head 159. The resultant error signal 518, proportional to the deviation and direction of the lower tumbler 159 from the set point, is transmitted to the position adjuster 484. The output of the position adjuster 484 is a contact closure of one of the relays 529 and 530. The relay 529 is energized when the value is greater than the set point; the relay 530 is energized when the value is less than the set point. Position-

ing of the cutter head 159 is accomplished by closing either the "raise" relay 529 or the "lower" relay 530 to energize the ladder hoist motor 400. At this "balanced" position, neither relay 529 nor 530 is closed. The position controller 484 has auto/manual "raise" and manual "lower" pushbuttons, deviation and position meters; and adjustable proportion reset and rate actions.

The after ladder suspension control module 495 is similar to the forward ladder suspension control module 494 except for the feedback position signals, which come from the hoist drum 168. The winch drum potentiometer 407 feeds the voltage-to-current converter 440 and the output signals from the converter 440 is the position-feedback signal 512 to the set point/auto-manual station 478.

The quarter and stern line control module 498 is similar to the after ladder suspension control module 495 except that the command signal 471 is made to provide three set point signals 501, 502 and 503. The position-feedback potentiometers 411, 410 and 412 feed the voltage-to-current converters 443, 444 and 445. The output of the voltage-to-current converters 443, 444 and 445 is the feedback signal 508, 509 and 510 to the respective set point/auto-manual stations 481, 482 and 483.

The articulation of two forward ladder sections, in place of one forward ladder section for the compensation of the pitch-and-swell, may simply be added to the control. The swell-and-pitch correction module 491 would have to have added one current source, one summing amplifier, two current multipliers and one signal characterizer. This will then provide a Y2' correction signal to the Y-coordinate command module 492. The Y-coordinate command module 492 would have added one current repeater and one summing amplifier.

For raising the ladder above water for maintenance and repairs to the cutter head 159, cutter drive, booster pump, pivot, etc., or for other reasons, manual control of the ladder hoists, quarter line and stern line winches may be employed, with the automatic compensating systems cut out.

Figure 6 shows some important details of a dredge like those of Figures 1, 2 and 3 in having the upper ladder section 153 connected to the dredge hull 151 at the pivot 155, with the lower ladder section 154 pivoted below it and articulated at the pivot 156. The cutter head 159 with its drive 160 is contained within and supported by the lower end of the ladder section 154. The suction pipe 157 runs from the back of the cutter head 159, through and supported by the ladder sections, 154 and 153, through the double bulk-heads of the hull 151 to the suction side of the main pump 158. The main pump and drive 200 is contained within the hull of the dredge. Flexible hose connections 202 are

located in the suction pipe 157 near the ladder pivot connections 155 and 156 to allow articulated motion of the ladder sections at these pivot points. The upper end of the ladder is secured to the hull 151 within the ladder well at the pivot connection 155. The lower end of the upper ladder section 153 supports the shaft 156 on which the clevised upper end 205 of the lower section of the articulated ladder is pivotally supported. Figure 8 shows the clevised upper end 205 of ladder section 154 connected to the lower end of section 153 by the shaft 156.

Figure 8 shows an alternate form of lower end digging device 203, namely, a conventional venturi-jet pump located just above the suction entrance to the pipe 157. Also shown are external high pressure water agitating nozzles to facilitate the picking up of the subaqueous material by the suction pipe 157.

Figure 9 also shows another alternate form of lower end digging device 204, namely a conventional type of bucket wheel with drive for digging the subaqueous material for pick-up and transport by suction pipe 157.

The booster pump 161 of Figure 1, and 215 of Figure 4, while not shown in Figure 6 can be of a conventional centrifugal or venturi-jet type. When dredging at depths of about eighty feet or more below water surface, some type of booster pump is required in the suction line to the main pump onboard the dredge to compensate for the increase in pipe friction at these greater depths. When dredging at greater depths two or more booster pumps in series may be utilized.

Figures 10 to 13 show a modified form of ladder suspension system having improved lateral stability. Instead of the suspension lines being parallel they are inclined to each other, though co-planar. Thus, two ladder sections 300 and 301, articulated together at 302, are supported by suspension system 303 and 304, respectively. The suspension system 304, includes two block-and-tackle lines 305 and 306 that are co-planar but converge together from their upper pulley blocks 307, 308, to a structure 313 supporting lower pulleys 311 and 312. The structure 313 is secured to the ladder 301 by suspension rods 314 and 315. As shown in Figure 10, the angle at which the lines 305 and 306 converge widens as the lines are shortened and the structure 313 and the ladder section 301 are raised. At all times lateral suspension stability is improved as compared with structures having parallel suspension lines.

This structure substantially eliminates all lateral bending moments in the dredge ladder, such as are imposed by the lateral digging forces as the dredge swings laterally or traverses from port to starboard and from starboard to port, in the process of excavating the subaqueous material. It also materially improves the structural integrity of the dredge

hull and superstructure as related to the ladder; this is especially important with sea dredges.

Attention is drawn to our co-pending Patent Application No. 34047/71 (Serial No. 1,359,828) which describes and claims floating deep-digging hydraulic ladder dredges having articulated dredge ladders such as are employed in the above-described embodiments of dredges according to the present invention.

WHAT WE CLAIM IS:—

1. A floating deep-digging dredge having a hull, a dredge ladder pivotally supported by the hull for relative swinging movement in a vertical plane only, and excavating means operative at the lower end of the ladder, such dredge including block-and-tackle suspension means for the ladder supported by superstructure on the hull and connected to the lower end of at least one swingable ladder section for support thereof, winch means for a cable of the block-and-tackle suspension means, sounding means for determining instantaneously the height of the hull above the bottom of the water on which the hull is floating, depth signal generating means actuated by the sounding means, angle sensing means for determining instantaneously the angle which the true horizontal makes with the nominally horizontal centre lines of the hull, angle signal generating means actuated by the angle sensing means, and control means receiving the depth signal and the angle signal and controlling the length of the suspension means to accommodate the ladder to swells in the water level on which the hull floats.

2. A dredge according to claim 1, including a stern line and two quarter lines for extending from respective sea bottom anchors to the dredge, a stern line winch and two quarter line winches for varying the length of the stern line and quarter lines, and means actuated by the control means for controlling the instantaneous length of the stern line and quarter lines during swells.

3. A dredge according to claim 2 having a plurality of swingable ladder sections each with its lower end connected to a respective suspension, wherein the depth signal generating means comprises first command means actuated by the sounding means, the angle signal generating means comprises second command means actuated by the angle sensing means, and the winch means comprises a separate luffline winch for each suspension, such dredge including third command means for setting a nominal position of the stern line and quarter line winches, additional command means, one for setting a nominal position of the stern line and quarter line winches, additional command means, one for setting a nominal position for each luffline winch, and control means connected to all of the command means and transmitting the settings



located in the suction pipe 157 near the ladder pivot connections 155 and 156 to allow articulated motion of the ladder sections at these pivot points. The upper end of the ladder is secured to the hull 151 within the ladder well at the pivot connection 155. The lower end of the upper ladder section 153 supports the shaft 156 on which the clevised upper end 205 of the lower section of the articulated ladder is pivotally supported. Figure 8 shows the clevised upper end 205 of ladder section 154 connected to the lower end of section 153 by the shaft 156.

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2. A dredge according to claim 1, including a stern line and two quarter lines for extending from respective sea bottom anchors to the dredge, a stern line winch and two quarter line winches for varying the length of the stern line and quarter lines, and means actuated by the control means for controlling the instantaneous length of the stern line and quarter lines during swells.

3. A dredge according to claim 2 having a plurality of swingable ladder sections each with its lower end connected to a respective suspension, wherein the depth signal generating means comprises first command means actuated by the sounding means, the angle signal generating means comprises second command means actuated by the angle sensing means, and the winch means comprises a separate luffline winch for each suspension, such dredge including third command means for setting a nominal position of the stern line and quarter line winches, additional command means, one for setting a nominal position of the stern line and quarter line winches, additional command means, one for setting a nominal position for each luffline winch, and control means connected to all of the command means and transmitting the settings

- of the third and additional command means to their winches by a series of outputs, the control means having means for superimposing on the outputs the effects of the first and
- 5 second command means, so that the nominal positions of the winches are kept changing to actual positions varying from the nominal positions by amounts such as are needed to keep the position of the excavating means substantially constant.
- 10

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