United States Patent [19]

McKay et al.

[11] 3,734,564

[45] May 22, 1973

[54] ENDLESS BUCKET DREDGE WITH ARTICULATED LADDER AND SWELL COMPENSATOR

[76] Inventors: **Cameron Edward McKay,** 1632 Coronado Way, Burlingame, Calif. 94010; **George Paton Barker,** Belmar, 85 Sauchenbush Road, Kirkcaldy, Fife, Scotland

[22] Filed: **Apr. 27, 1970**

[21] Appl. No.: **31,945**

[52] **U.S. Cl.** **299/9,** 37/69, 198/94, 254/172

[51] **Int. Cl.**.....**E02f 3/14,** E02f 3/16, E02f 7/06

[58] **Field of Search**.....37/72, 58, 60, 69, 37/191, 192; 299/9; 175/89, 90; 254/172; 198/94

[56] **References Cited**

UNITED STATES PATENTS

3,579,872	5/1971	Jantzen	37/72 X
246,362	8/1881	Angell	37/69
2,620,575	12/1952	Pace	37/83 X
3,057,484	10/1962	Trevisan	212/58 X
288,091	11/1883	Menge	37/69
1,762,794	6/1930	Perry	37/69
3,146,537	9/1964	Von Bolhar	37/69
1,739,326	12/1929	Posselt	37/69 UX
1,154,545	9/1915	Penedo	37/69
3,512,281	5/1970	Hadjidakis	37/72 X
318,859	5/1885	Bowers	37/72 UX
3,350,798	11/1967	Nelson	37/65

FOREIGN PATENTS OR APPLICATIONS

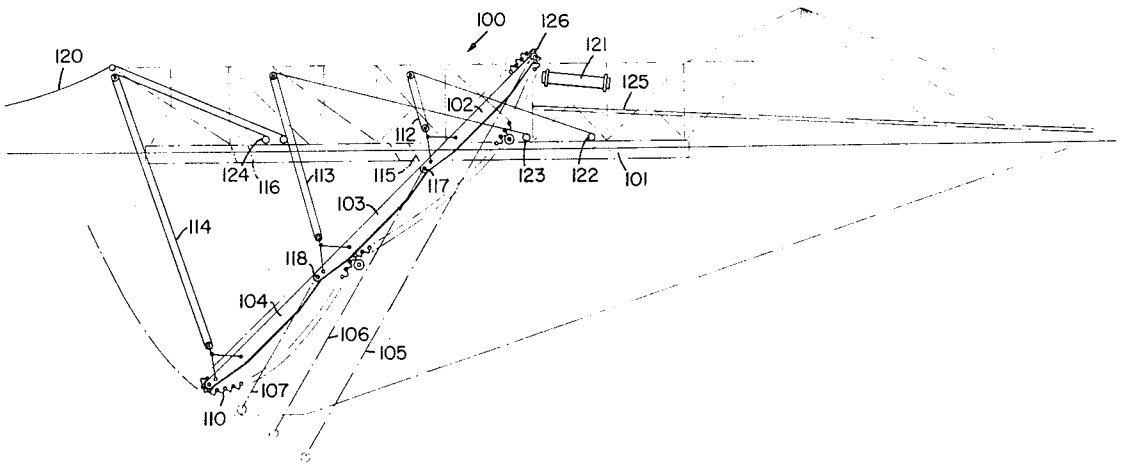
627,021	3/1936	Germany	37/191 R
1,159,336	7/1969	Great Britain	299/9
1,273,436	7/1968	Germany	37/72
717,862	11/1954	Great Britain	37/72
1,249,175	8/1967	Germany	37/58
1,409,657	10/1968	Germany	37/72

Primary Examiner—Robert E. Pulfrey
Assistant Examiner—Clifford D. Crowder
Attorney—Owen, Wickersham & Erickson

[57] **ABSTRACT**

A deep-digging floating dredge having an articulated ladder with two or more sections pivoted together for relative swinging movement in a vertical plane only and a digging bucket line supported by the ladder. The dredge ladder may have a fixed uppermost section, with either the same or a different bucket line. For sea-going use the dredge may have sounding means for determining instantaneously the height of the hull above the bottom of the water on which the hull is floating, angle sensing means for determining instantaneously the angle to the horizontal of the upper movable ladder section, and control means receiving an input depth signal and an input angle signal controlling the suspension length of the articulated ladder sections and accommodating it to swells in the water level on which the hull floats.

30 Claims, 27 Drawing Figures



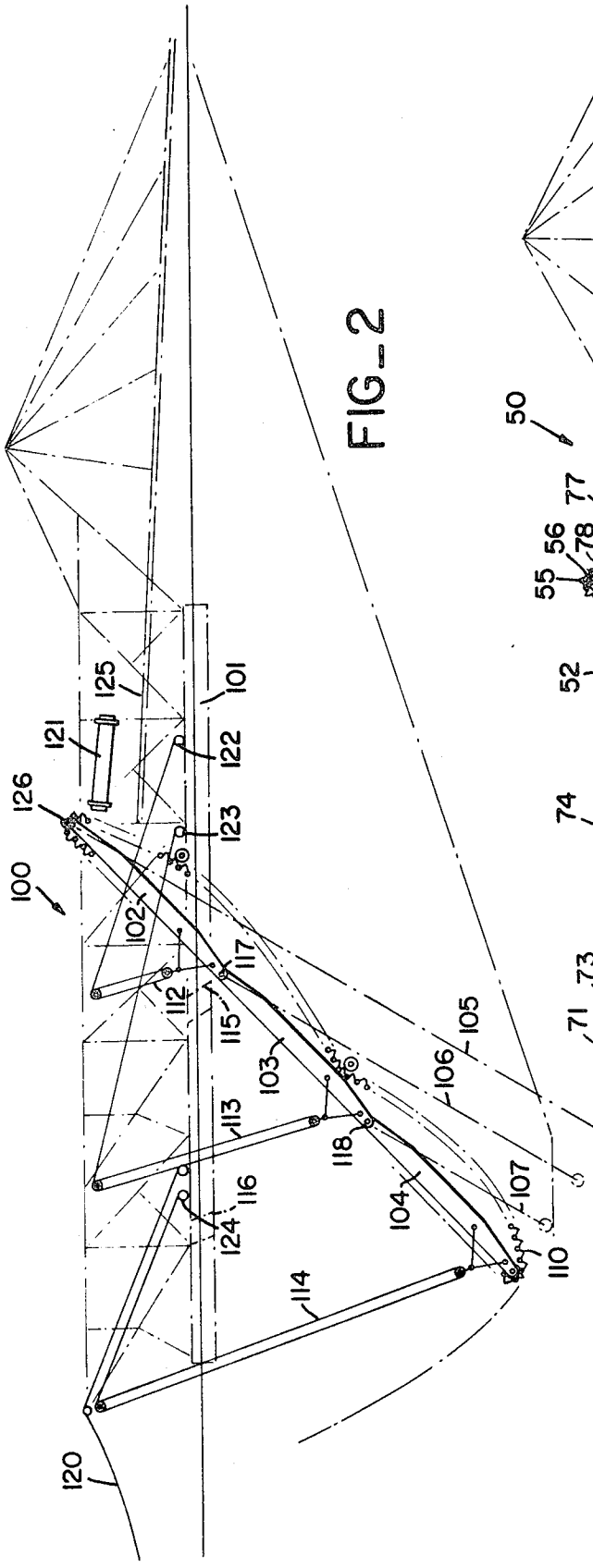


FIG_2

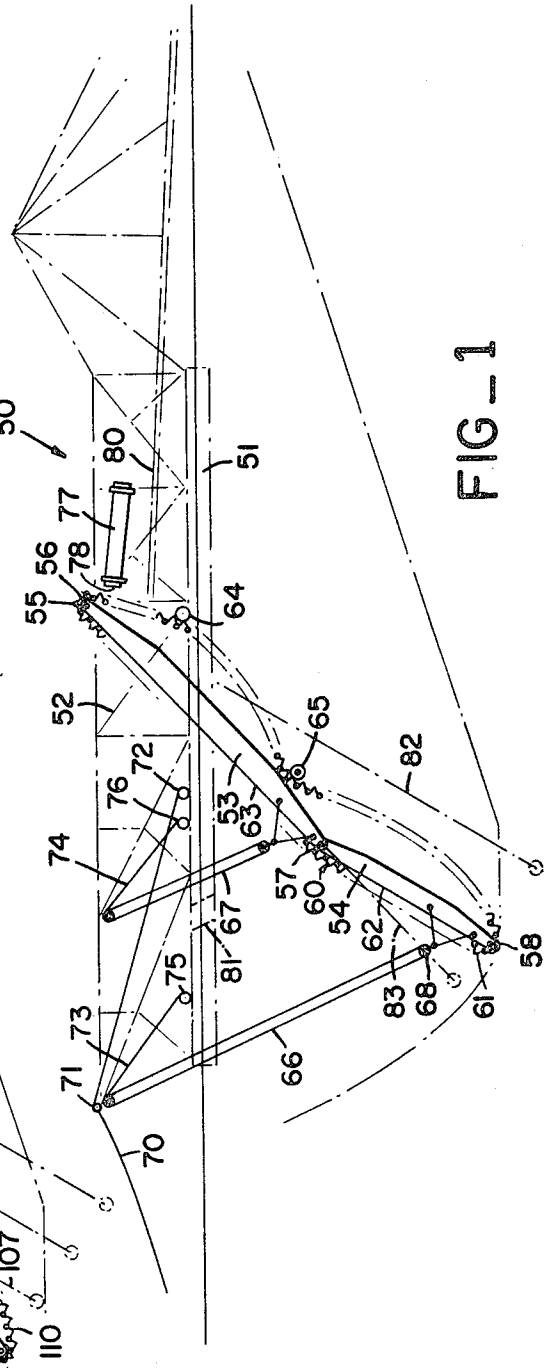


FIG_1

INVENTORS
CAMERON E. McKAY
GEORGE P. BARKER

BY

Owen, Wickersham & Erickson

ATTORNEYS

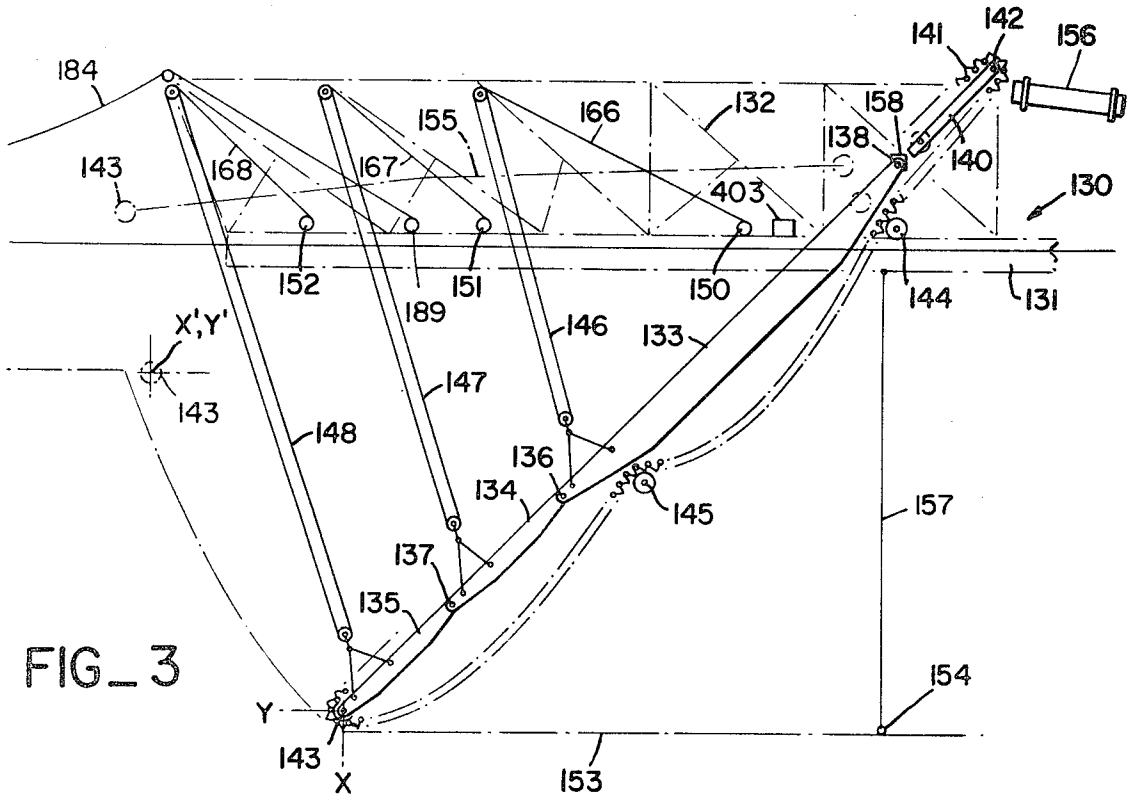

184
143
168
167
155
166
132
158
138
140
141
142
156
130
403
152
189
151
150
144
131
X',Y'
143
146
133
147
148
136
134
145
157
137
135
154
Y
143
X
153

FIG_3

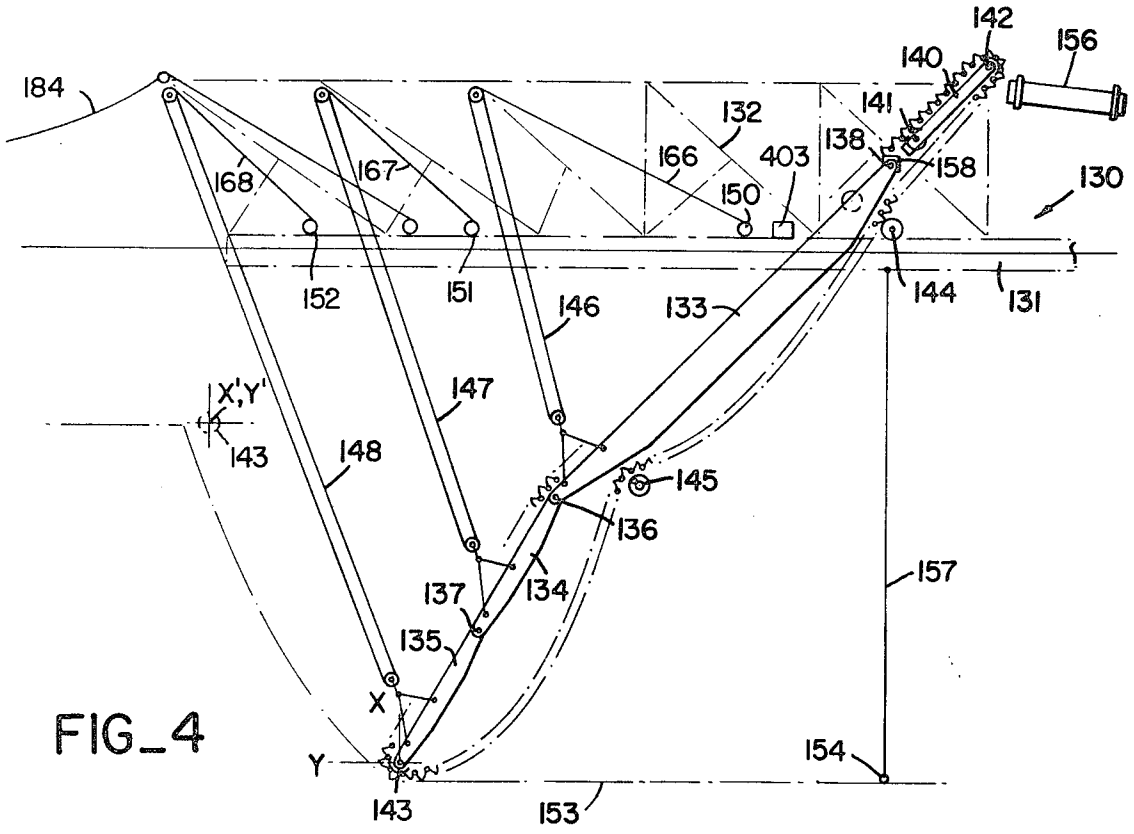

184
168
167
132
166
403
150
140
141
142
156
138
158
130
152
151
146
133
144
131
X',Y'
143
147
148
145
136
157
137
134
135
X
Y
154
143
153

FIG_4

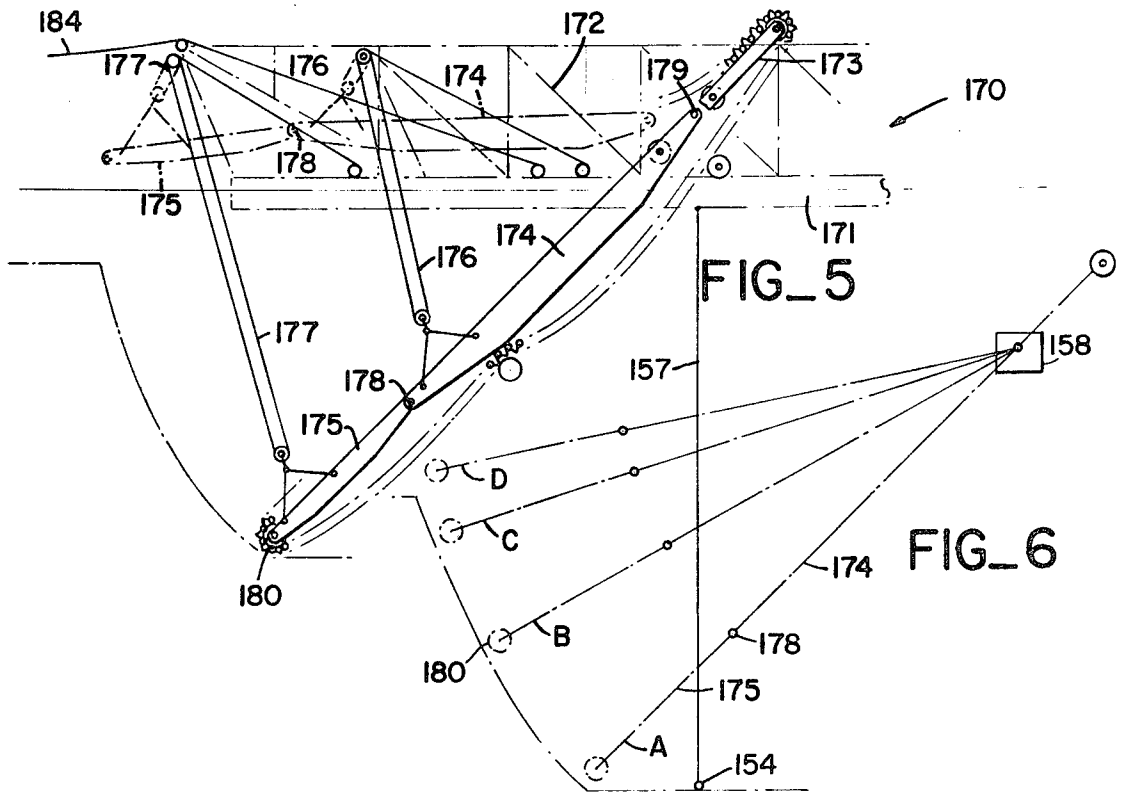


FIG_5

FIG_6

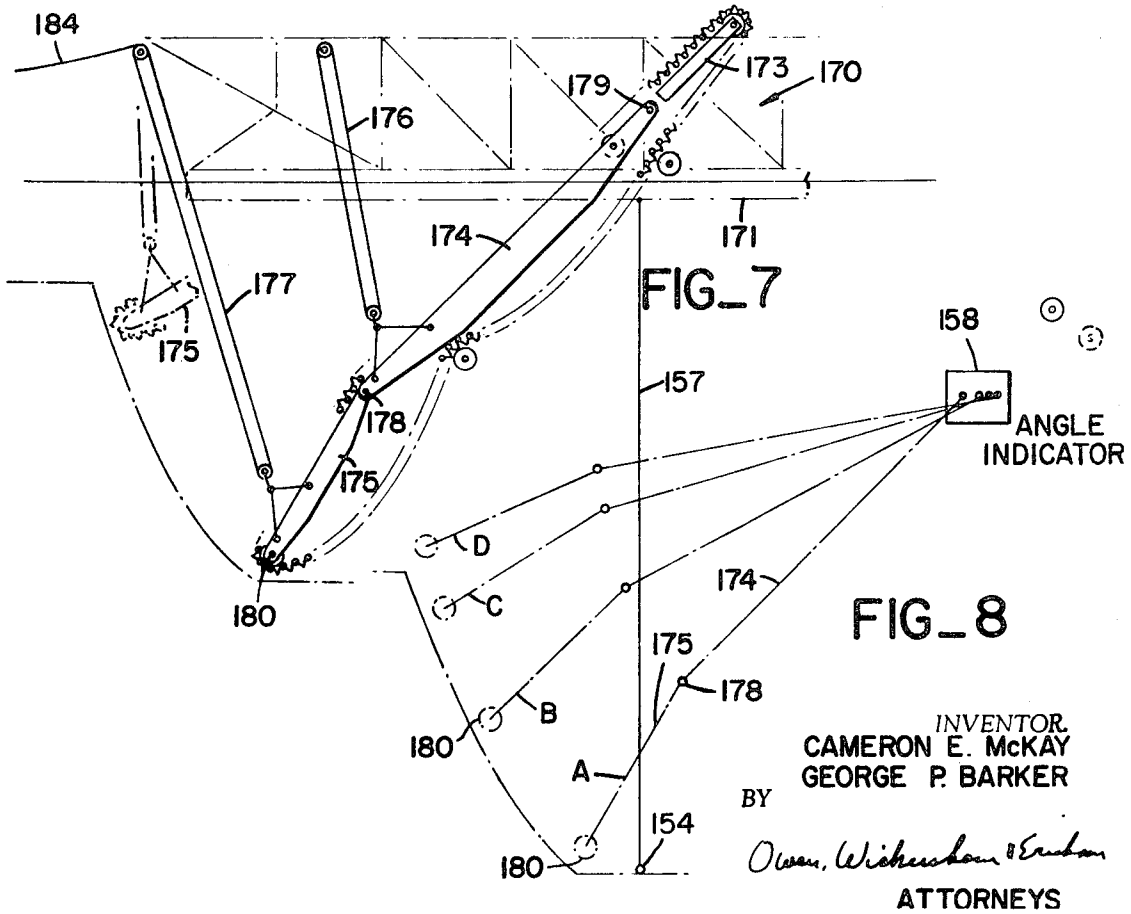


FIG_7

FIG_8

INVENTOR.
CAMERON E. McKAY
GEORGE P. BARKER
BY
Owen, Wickersham & Erickson
ATTORNEYS

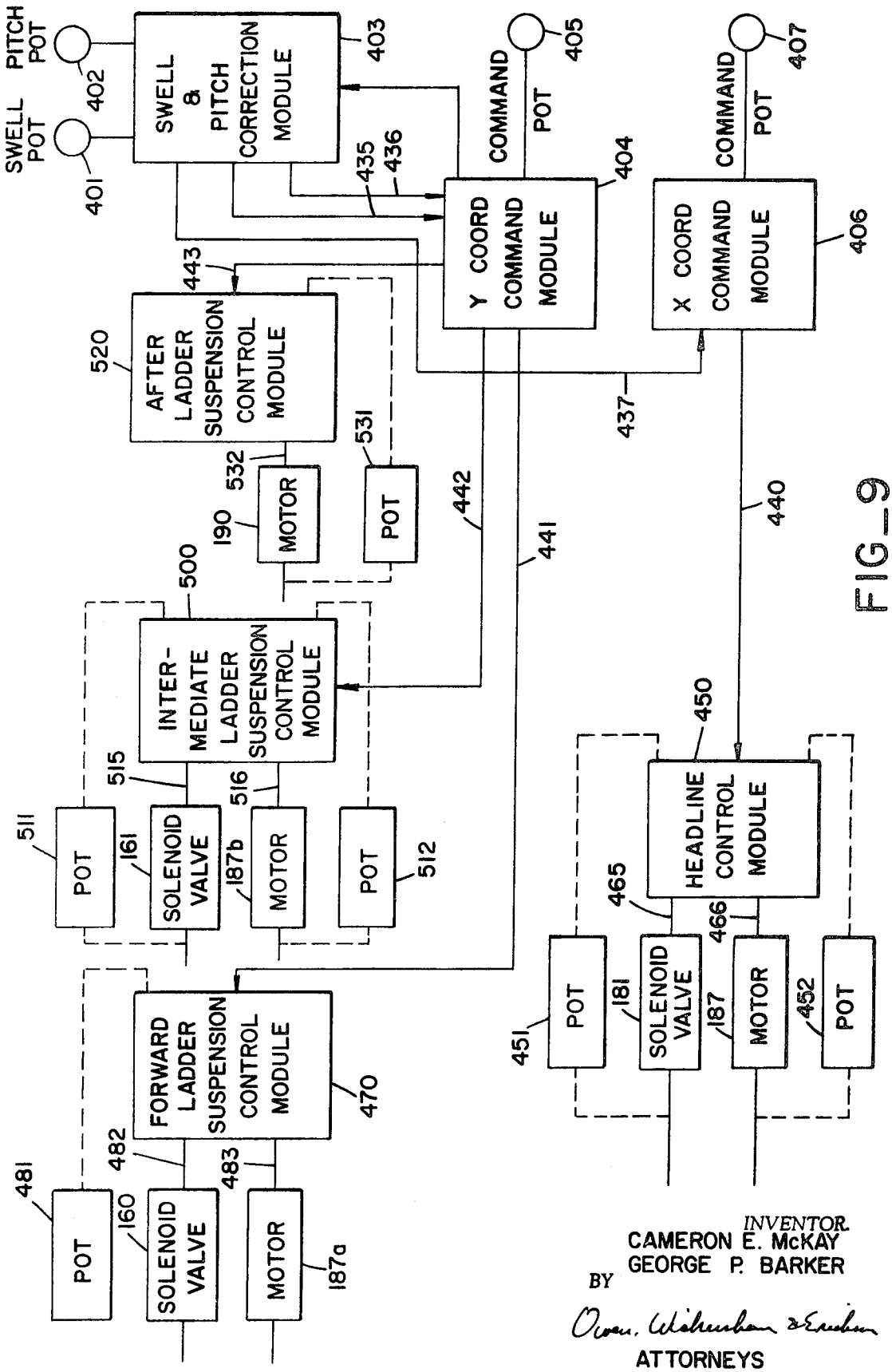


FIG_9

INVENTOR.
CAMERON E. McKAY
GEORGE P. BARKER

BY

Owen, Wickersham & Erickson

ATTORNEYS

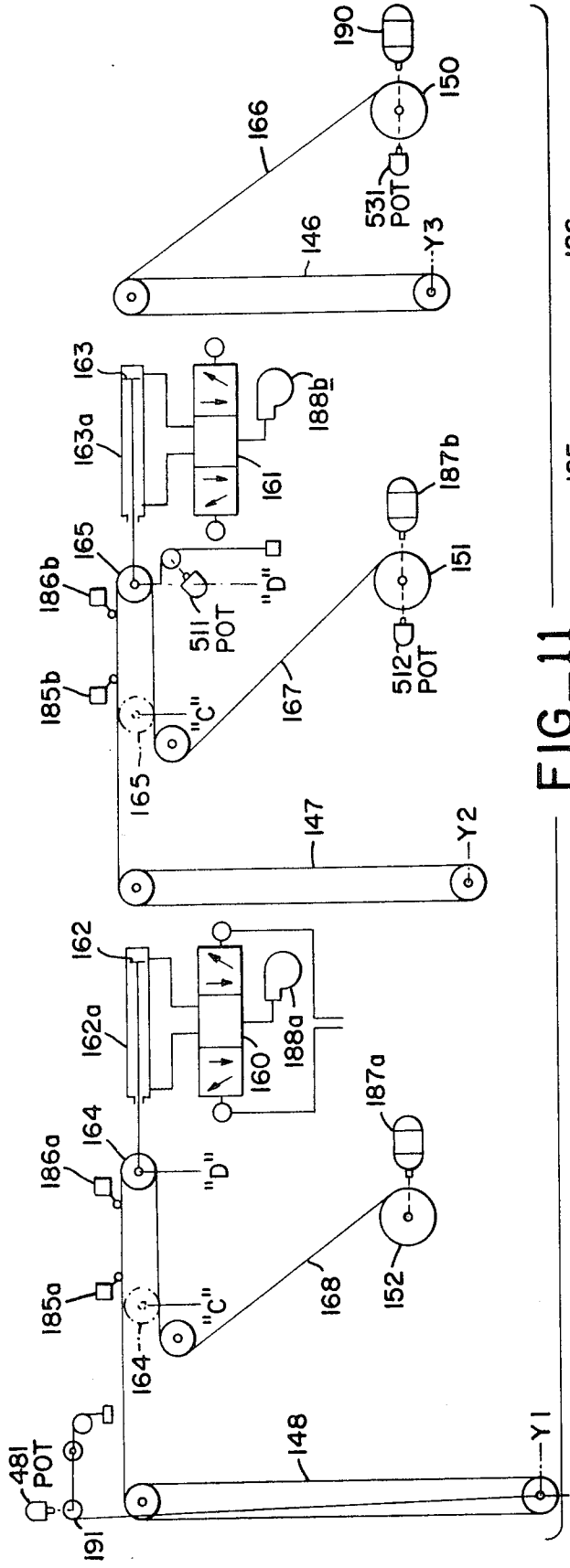


FIG_11

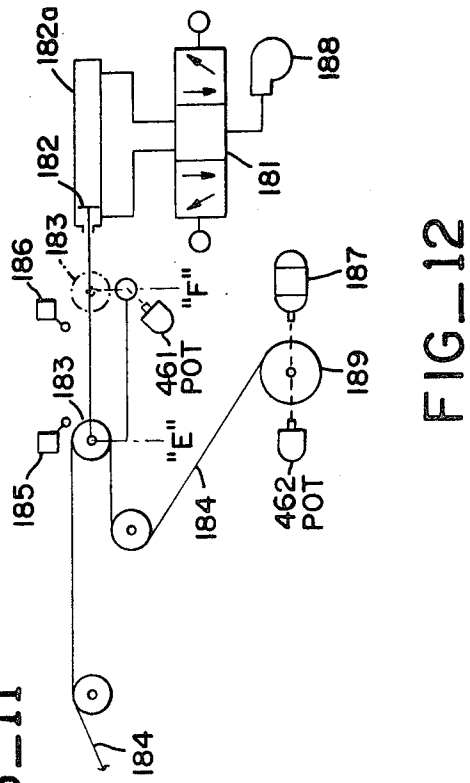


FIG_12

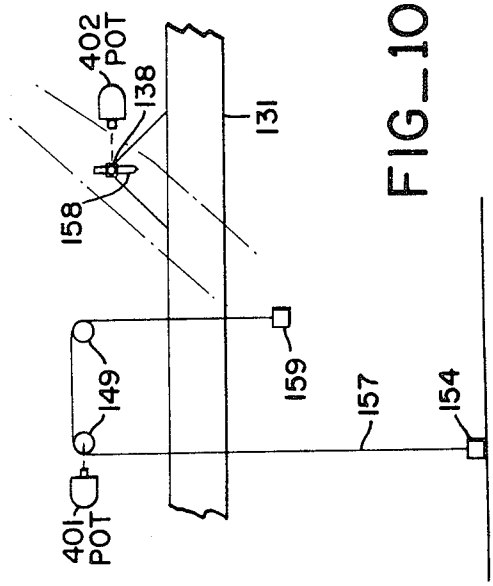


FIG_10

INVENTORS
CAMERON E. McKAY
GEORGE P. BARKER

BY

Owen, Wickersham & Erickson

ATTORNEYS

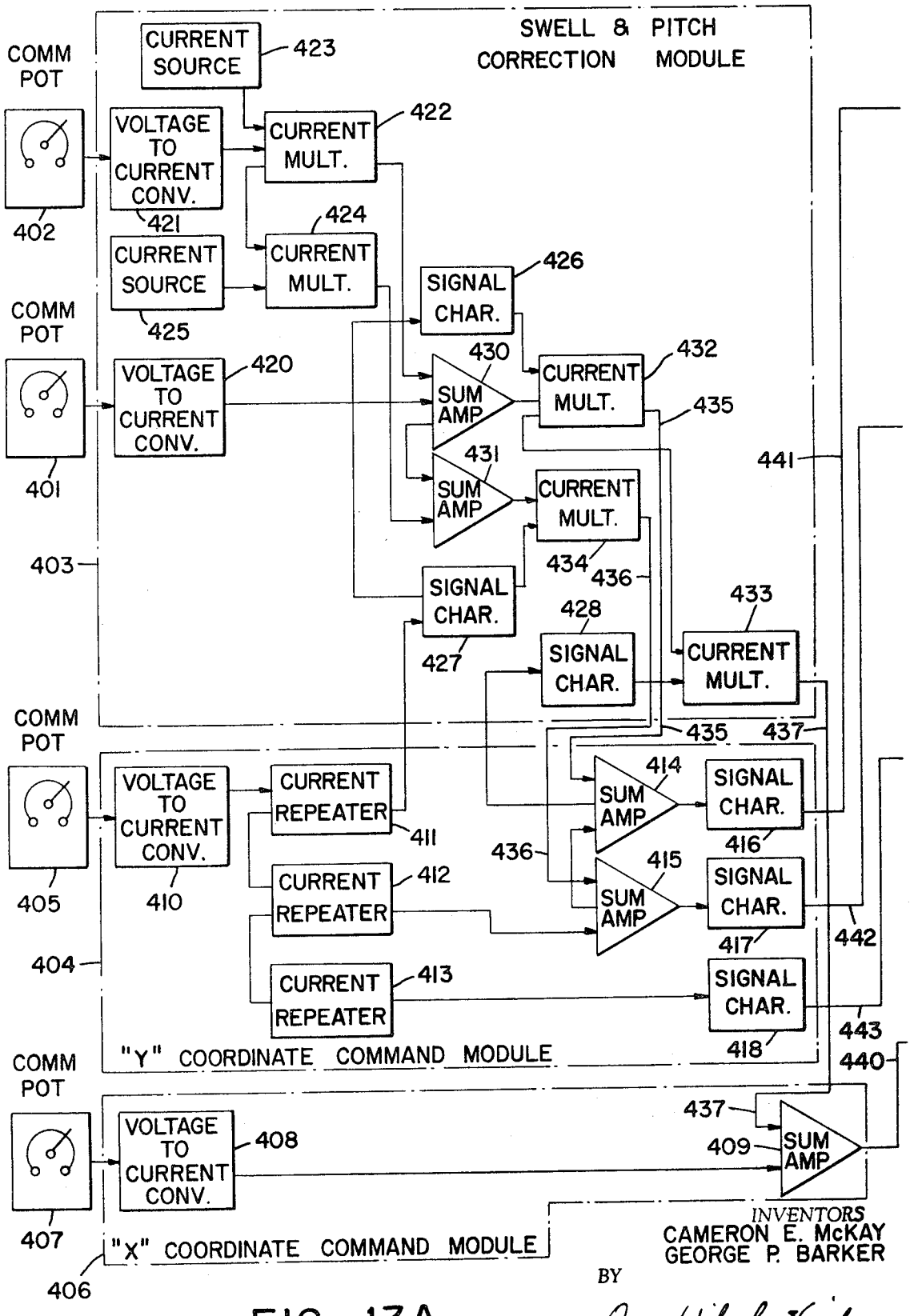


FIG_13A

INVENTORS
CAMERON E. McKAY
GEORGE P. BARKER
BY
Owen, Wickenden & Erickson
ATTORNEYS

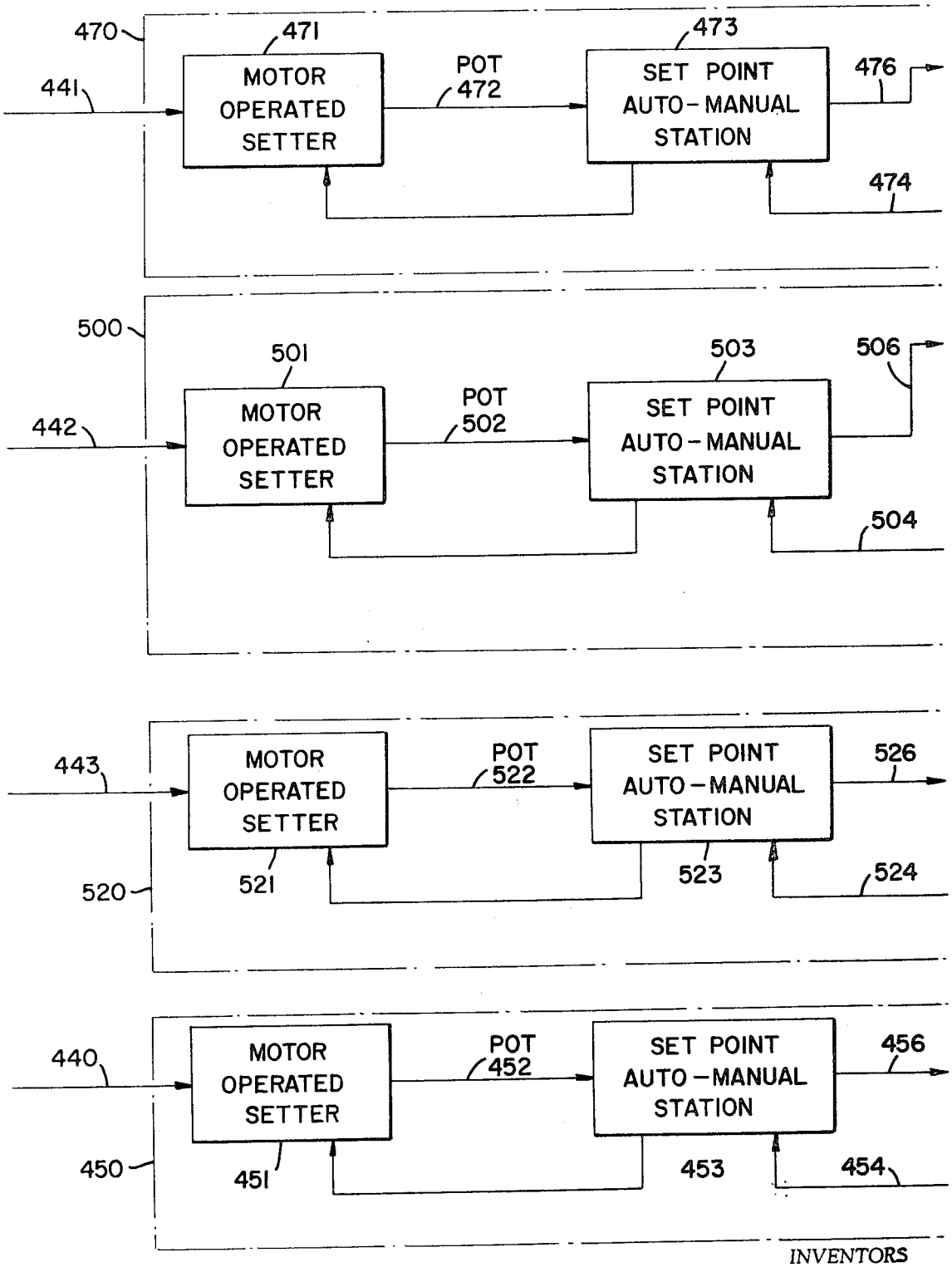


FIG_13B

INVENTORS
CAMERON E. McKAY
GEORGE P. BARKER
BY
Owen, Wickersham & Erickson
ATTORNEYS

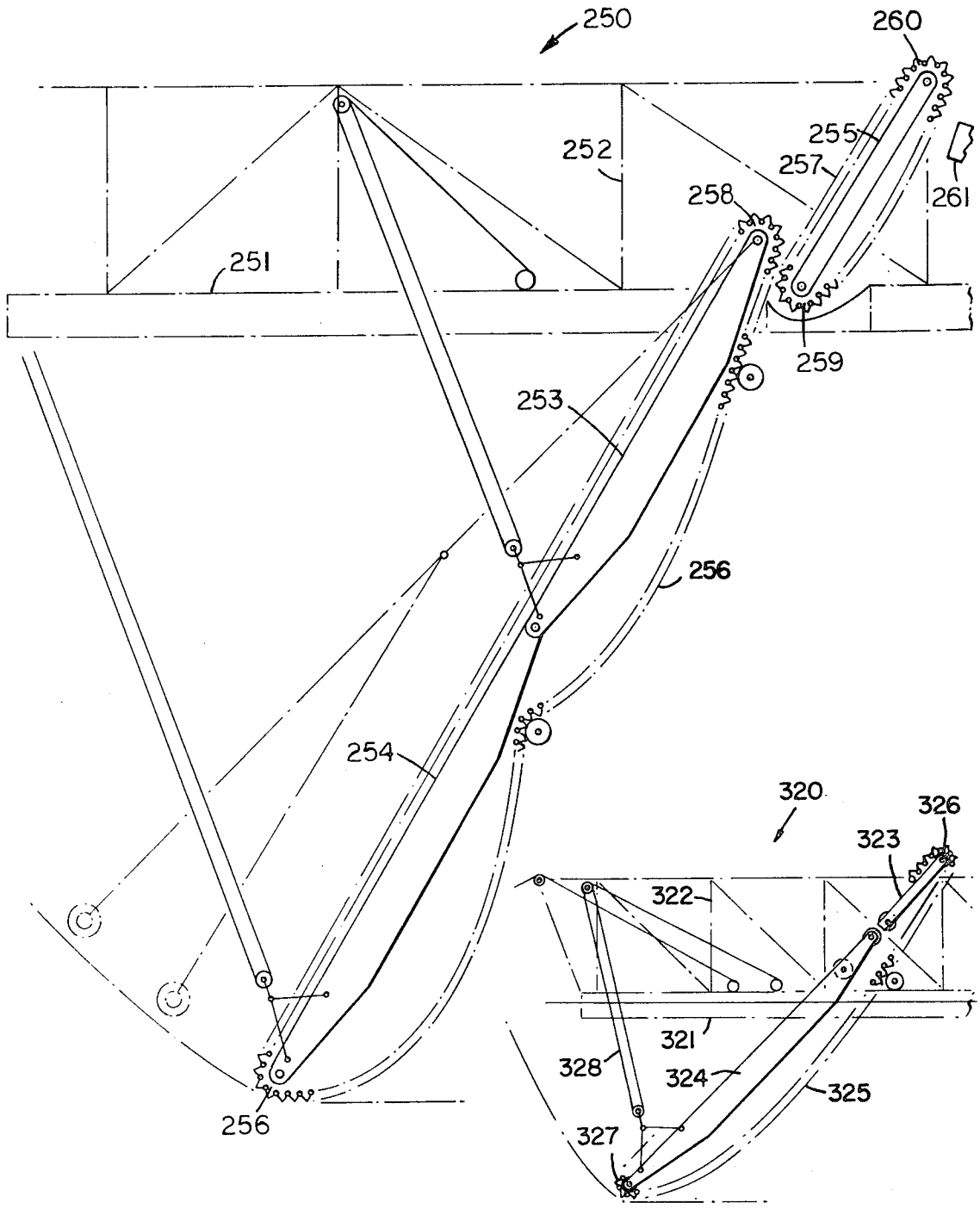


FIG_14

FIG_25

INVENTOR.
CAMERON E. McKAY,
GEORGE P. BARKER
BY
Owen, Wickersham & Erickson
ATTORNEYS

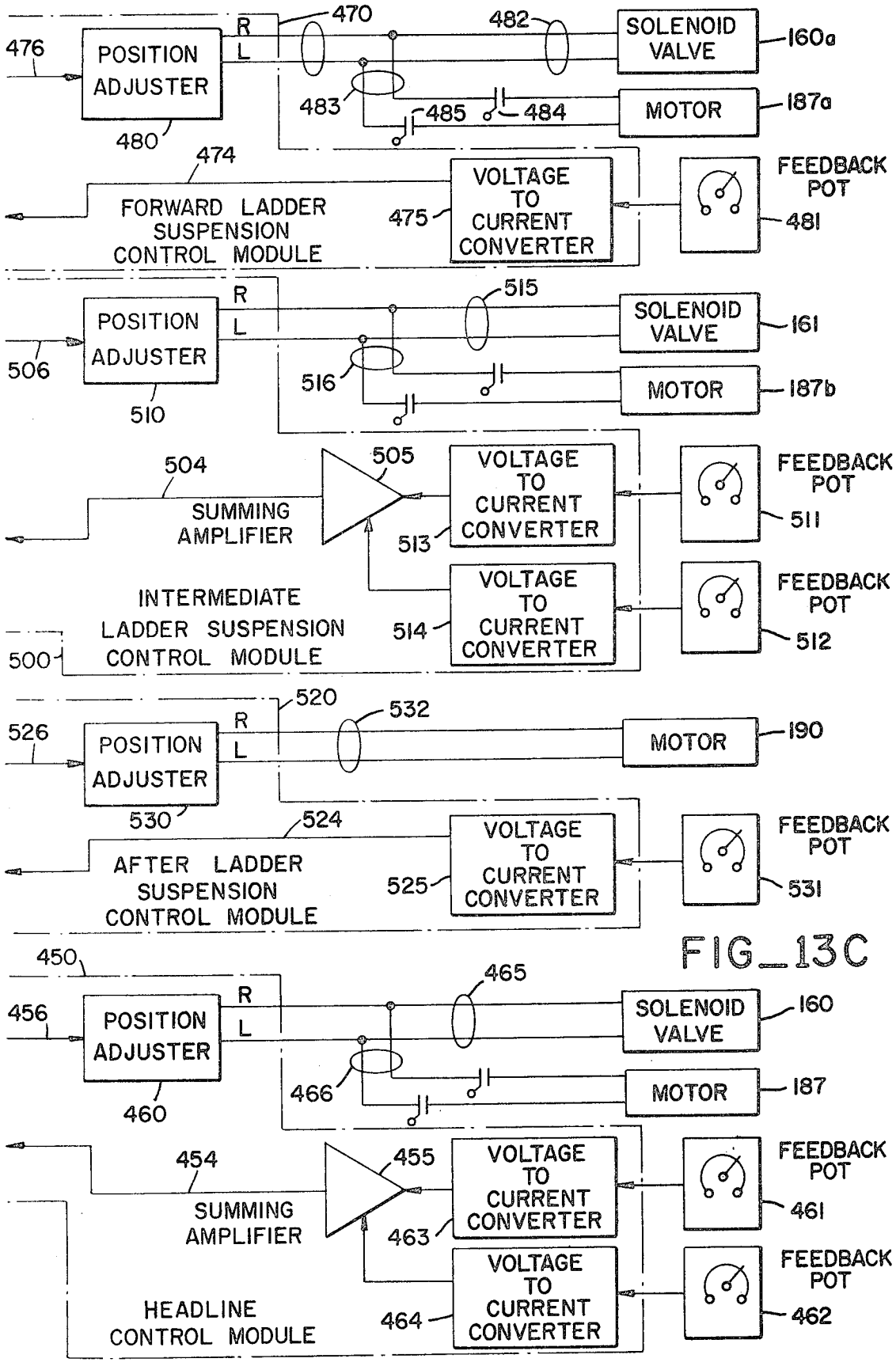

476
POSITION ADJUSTER
480
R
L
470
482
SOLENOID VALVE
160a
483
485
484
MOTOR
187a
474
FORWARD LADDER SUSPENSION CONTROL MODULE
475
VOLTAGE TO CURRENT CONVERTER
FEEDBACK POT
481
506
POSITION ADJUSTER
510
515
SOLENOID VALVE
161
516
MOTOR
187b
504
SUMMING AMPLIFIER
505
513
VOLTAGE TO CURRENT CONVERTER
FEEDBACK POT
511
INTERMEDIATE LADDER SUSPENSION CONTROL MODULE
500
514
VOLTAGE TO CURRENT CONVERTER
FEEDBACK POT
512
526
POSITION ADJUSTER
530
520
532
MOTOR
190
524
AFTER LADDER SUSPENSION CONTROL MODULE
525
VOLTAGE TO CURRENT CONVERTER
FEEDBACK POT
531
450
456
POSITION ADJUSTER
460
465
SOLENOID VALVE
160
466
MOTOR
187
454
SUMMING AMPLIFIER
455
463
VOLTAGE TO CURRENT CONVERTER
FEEDBACK POT
461
HEADLINE CONTROL MODULE
464
VOLTAGE TO CURRENT CONVERTER
FEEDBACK POT
462

FIG_13C

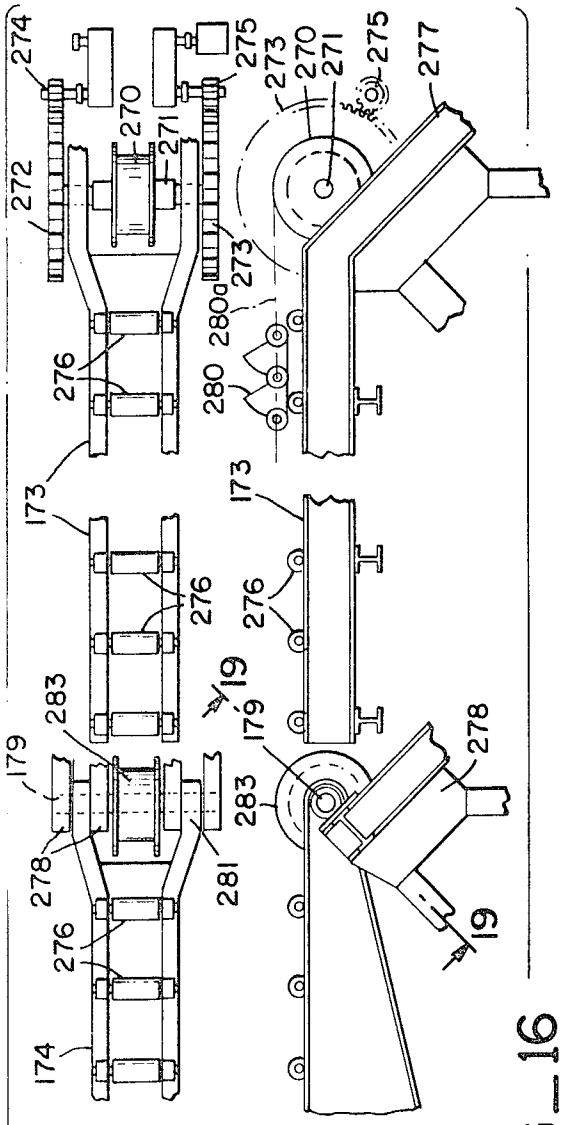


FIG_16

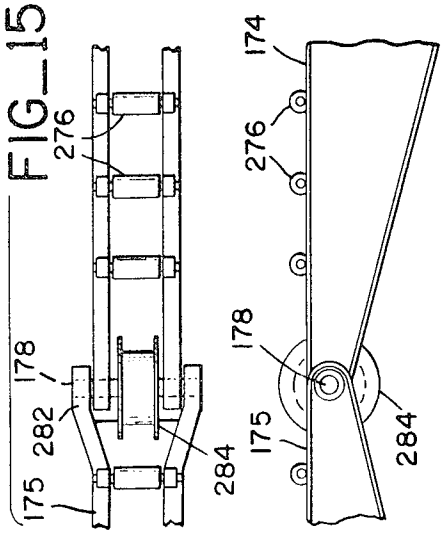


FIG_15

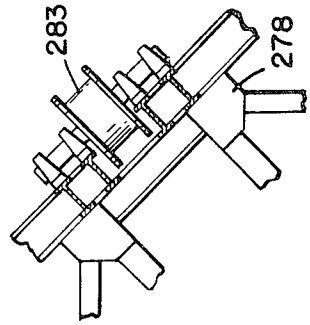


FIG_19

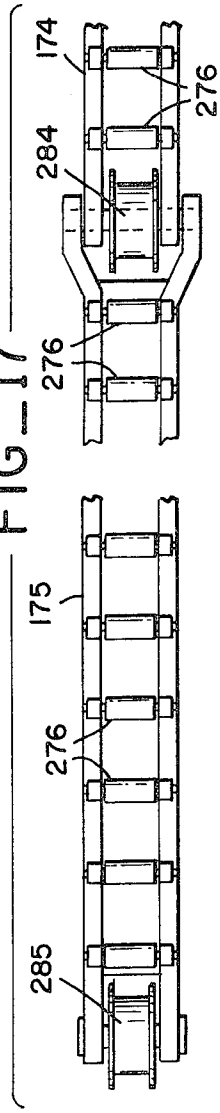


FIG_17

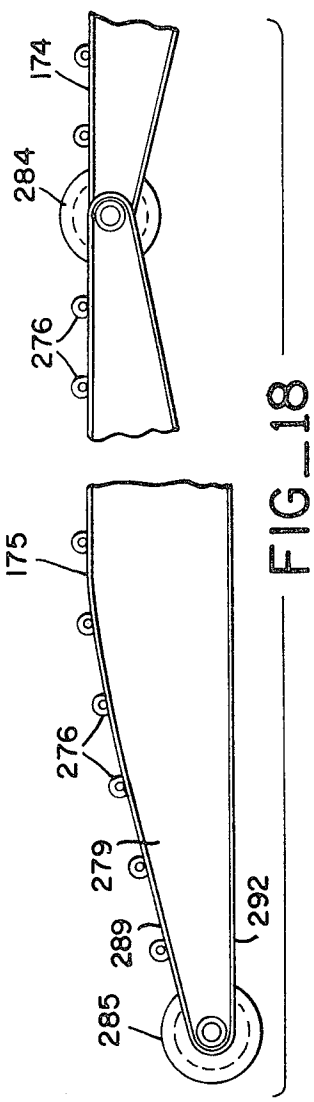
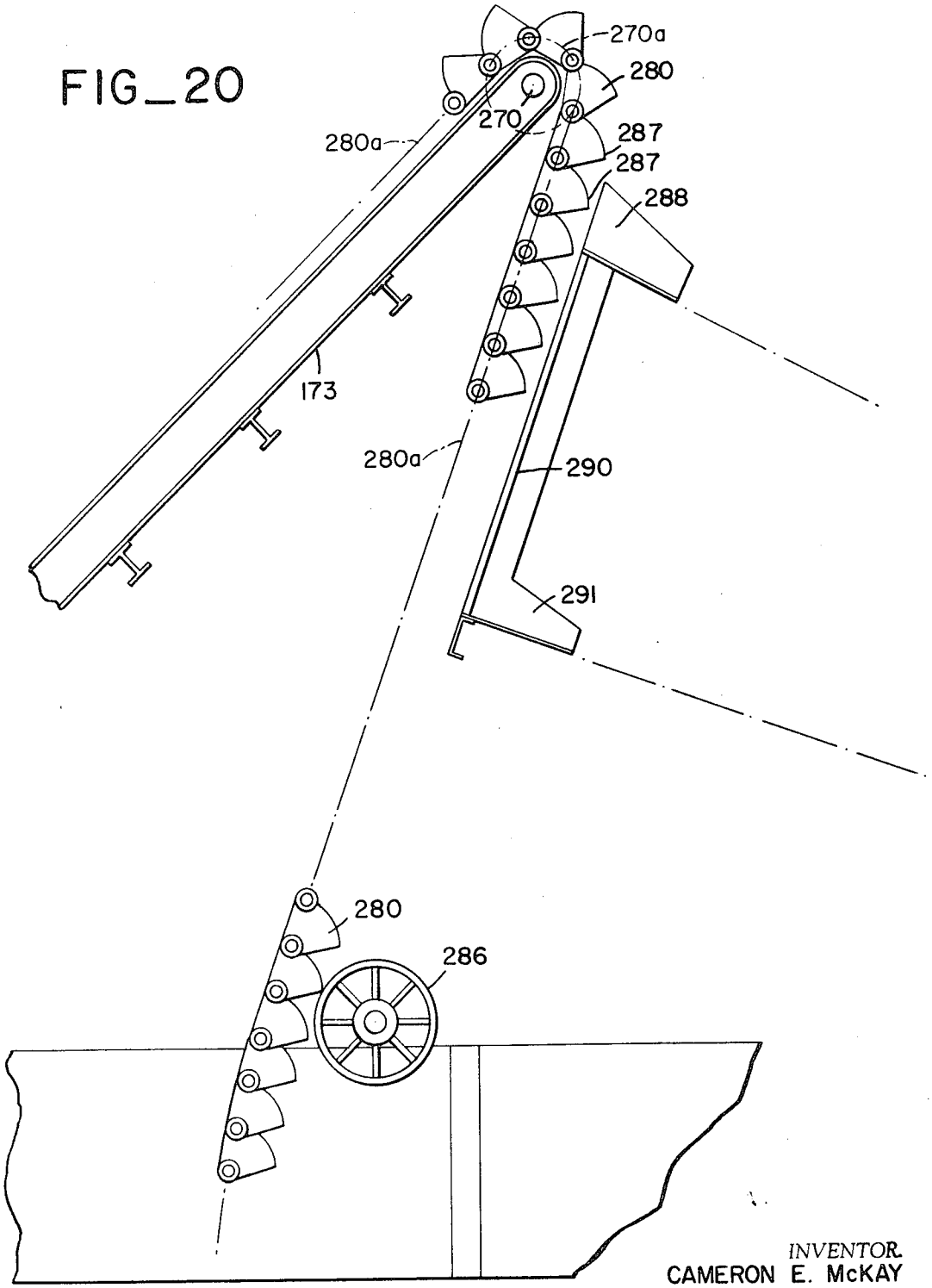


FIG_18

INVENTORS
CAMERON E. McKAY
GEORGE P. BARKER

BY
Owen, Wickersham & Erickson
ATTORNEYS

FIG_20



INVENTOR.
CAMERON E. McKAY
GEORGE P. BARKER
BY
Owen, Wickenden & Erickson
ATTORNEYS

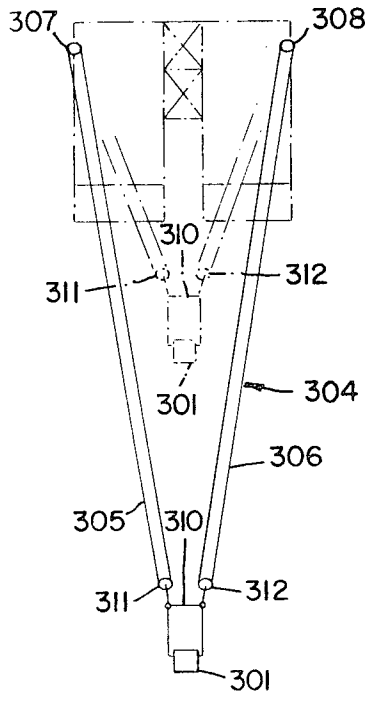


FIG_21

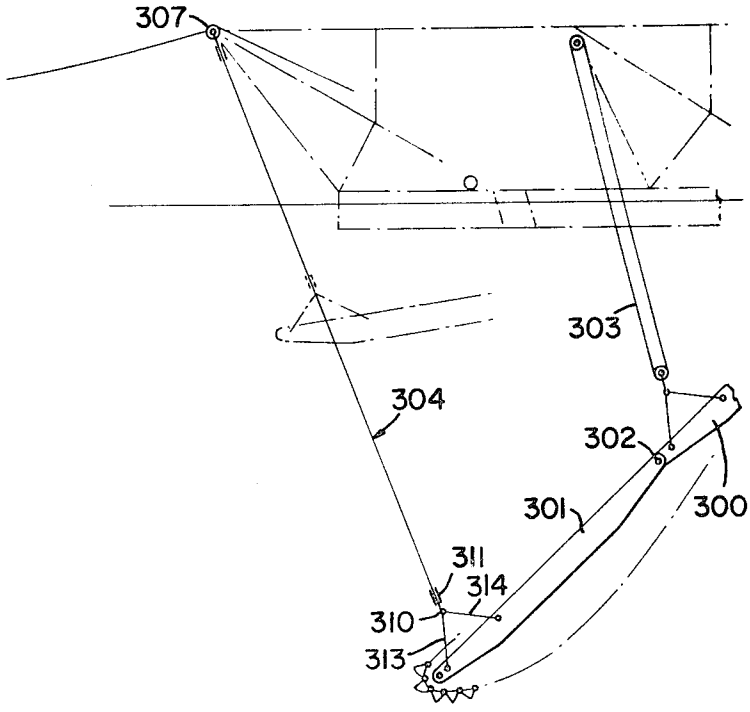


FIG_22

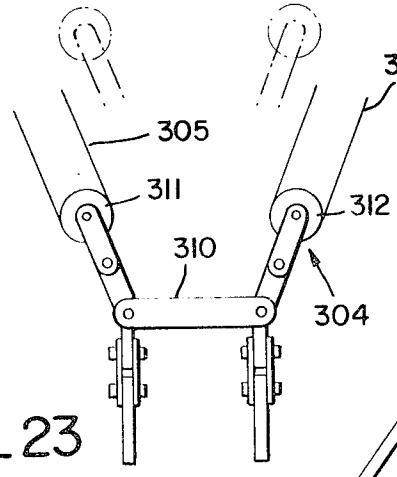


FIG_23

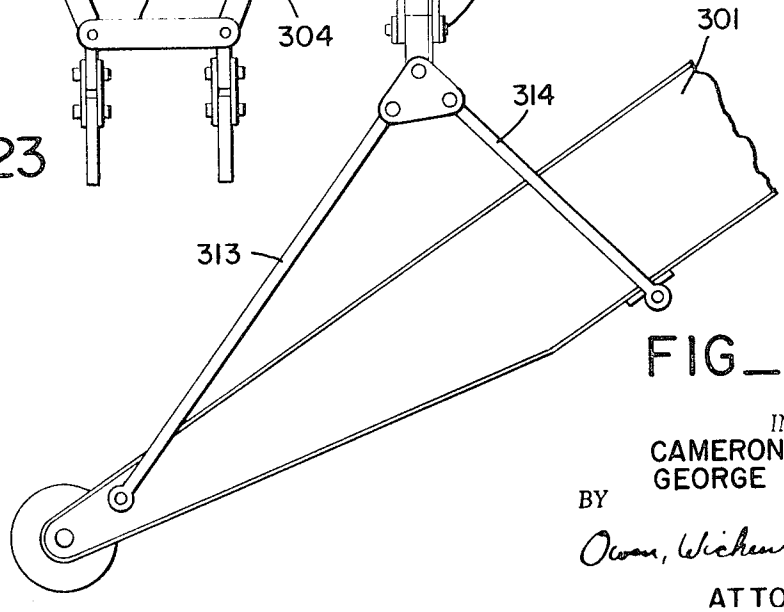


FIG_24

INVENTORS
CAMERON E. McKAY
GEORGE P. BARKER
BY
Owen, Wickenden & Gaulkin
ATTORNEYS

ENDLESS BUCKET DREDGE WITH ARTICULATED LADDER AND SWELL COMPENSATOR

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

BACKGROUND OF THE INVENTION

While dredges have been used for many years in gold mining and other similar mining operations, they have heretofore been confined to relatively shallow depths and to relatively quiet waters. Depths up to about 60 to 80 feet have long been dredged successfully, but beyond a depth of about ninety feet below water level, the unit cost of dredging has increased sharply, and such deep-water dredging has become much less economical. As one goes still deeper the costs increase disproportionately.

Thus, although a few dredges have been operated as deeply as about 125 feet below water level, they have not been operated much below that depth for several reasons. For one thing, the manufacturing cost for dredges of prior-art designs capable of digging below about 125 feet below water level was in itself so high as to make the venture uneconomical. Very heavy high-strength ladder girders had to be provided if the large-magnitude live and dead load forces were to be withstood. Structures that were efficient for depths of 75 to one hundred feet would not be adequate or efficient at depths of 125 feet and greater. When the dredges were made according to prior-art designs, every additional foot added costs and inefficiencies. Similarly, operating costs of such prior-art structures were also intolerable.

Dredges have encountered problems other than those of depth alone. For example, in operations where the water is not a quiet pond, particularly with offshore 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 a swell or wave would rise, the digging buckets would be lifted from engagement with the sand, soil or rock, and so a large proportion of the time the buckets would come up empty or with only a small proportion of their capacity filled; the alternative to this would have damaged the buckets, the ladder, and related structural and mechanical components by having the buckets 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 waters, even though it was often well known that in many instances really valuable minerals lay more than a hundred feet below the surface of the ocean in exposed waters which might be fairly close to shore.

SUMMARY OF THE INVENTION

The present invention provides a novel articulated ladder structure and other significant structural features in a combination which make deep digging — down to two hundred feet and more below water level — quite practical and economical. The large cross-sectional ladder girder thicknesses and the excessive weights that would be required by prior-art structures are avoided and made unnecessary for using articulated structures; thus, the ladders of this invention are provided in a plurality of sections, two or three usually

being sufficient, depending upon the total depth needed. By combining these plural sections with adequate rigging lines and maneuvering lines, the depth can be extended at costs that are far less than what one familiar with prior-art structures would have expected. The invention becomes quite significant in locations where it is known that there are extensive deposits of precious metals, gems, commercial minerals, sand, or gravel, or any other subaqueous deposits of commercial value, at depths too great to be accessible at economic costs to the prior-art dredges. The invention is also applicable to dredges utilized for marine construction in excavating both offshore and inland waters.

In the present invention, not only can greater depths be attained, as indicated earlier, but in offshore dredges compensation can be made so that the digging engagement of the dredge buckets, 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 of this invention can operate efficiently even with relatively high swells and even where the minerals lie well below the surface of the sea. The invention provides a compensating mechanism which is sensitive to swells and waves and which acts to change the angle of the dredge ladder and its approach sufficiently to keep the digging buckets in engagement with the material being dredged.

In connection with these major features of the invention — the employment of articulated dredges to get greater depth and the swell-compensating mechanism to enable operation in offshore waters — the invention includes a number of other significant features. As noted below, these features materially improve the performance and the economics of the dredges of this invention and give improved performance with lower overall costs.

Insofar as the invention relates to offshore dredging, it applies not only to bucket line dredges, but to any kind of floating ladder dredge; insofar as it relates to deep dredging other than offshore dredging, that is, where the dredge operates in a pond or river where the water level changes very slowly, the invention is particularly directed to bucket-type dredges.

Other objects and advantages of the invention will appear from the following description of some preferred forms thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a simplified view in side elevation of a deep-water dredge, for use in relatively quiet waters, embodying the principles of the invention and having an articulated ladder in two sections.

FIG. 2 is a view similar to FIG. 1 of a modified form of dredge for use in relatively quiet waters in which the ladder is made in three articulated sections.

FIG. 3 is a view similar to FIG. 2 of an offshore dredge embodying the principles of the invention, made in three articulated sections, with an additional fixed ladder section at the top, above the uppermost of the three movable ladder sections. In this view the four ladder sections are all aligned in a straight line.

FIG. 4 is a view similar to FIG. 3 of the dredge of FIG. 3 in a position where the two lower sections are

inclined downwardly relative to the upper two sections, in order to compensate for a swell.

FIG. 5 is a view similar to FIG. 3 of an offshore dredge having two movable sections with a fixed ladder section thereabove. The view shows the movable ladder portions in two different positions, the lower position being shown in solid lines and the upper one in broken lines.

FIG. 6 is a diagrammatic view illustrating four different positions of the dredge ladder of FIG. 5, all with the two movable ladder sections kept in a straight line.

FIG. 7 is a view similar to FIG. 5, with the dredge of FIG. 5 shown with the lower movable ladder section inclined downwardly from the upper movable ladder section to compensate for a swell. An upper position of the lower movable ladder section is shown in broken lines.

FIG. 8 is a diagrammatic view illustrating four different positions where the angle between the two ladder sections remains as in FIG. 7.

FIG. 9 is a block diagram of control apparatus for obtaining compensation for swell through the ladder suspensions and headline in the dredge of FIGS. 3 and 4.

FIG. 10 is a diagrammatic view in elevation of the input system for the compensation apparatus of FIG. 9.

FIG. 11 is a diagrammatic view in elevation of the ladder-suspension control apparatus of FIG. 9.

FIG. 12 is a diagrammatic view in elevation of a headline compensating apparatus used in the control of FIG. 9.

FIGS. 13A, 13B and 13C comprise an electrical circuit diagram for the device of FIG. 9 to 12.

FIG. 14 is a view in side elevation of a modified form of dredge having two movable ladder sections and a secondary fixed-position ladder to which the upper of the two movable sections transfers the bucket load.

FIG. 15 is an enlarged view of the fixed ladder ramp and the upper portion of the articulated pivoted ladder sections, broken twice in the middle and at each end of the frame, also showing the upper tumbler and its drive machinery, the upper pivoted connection of the swingable ladder, and the intermediate pivoted connection for the articulated ladder sections.

FIG. 16 is a similar view of the same parts in side elevation.

FIG. 17 is a view similar to FIG. 15 of the lower portion of the articulated ladder, broken in the middle of the framework, also showing an optional form of combined ladder end and an optional form of bucket idler located at the pivotal connection of the articulated ladder sections.

FIG. 18 is a view similar to FIG. 17, showing the same parts in side elevation.

FIG. 19 is a view in section taken along the line 19—19 in FIG. 16, showing the independent structural supports for both the fixed upper ladder ramp and the upper pivoted connection of the swingable ladder.

FIG. 20 is an enlarged fragmentary view in side elevation of the upper part of the fixed ramp ladder generally like that of FIG. 15, but with a modification incorporating, in addition to the main discharge chute, a series of save-all grizzly bars and a save-all collection chute.

FIG. 21 is a fragmentary top plan view of a dredge having a skew suspension for its lowermost articulated ladder section.

FIG. 22 is a similar view in side elevation.

FIG. 23 is a detailed fragmentary view of the connection of the suspension to the lowermost ladder section.

FIG. 24 is a fragmentary view in side elevation enlarged with respect to FIG. 22.

FIG. 25 is a view similar to FIG. 5 of a dredge having a fixed upper ramp and a single swingable ladder section.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The dredge 50 of FIG. 1, which is designed for deep dredging in relatively quiet waters, such as a pond, a sheltered bay, or a river where the water level changes rather slowly, has a hull 51 with superstructure 52. The hull 51 and the superstructure 52 support the uppermost of two articulated ladder sections 53 and 54 by means of a pivot axis member 55 at the top of the upper ladder section 53, which may also provide the axis of rotation of an upper tumbler 56. The lower ladder section 54 is attached to the lower end of the upper ladder section 53 by a pivot member 57, and it carries a lower tumbler 58 at its lower end. A single continuous bucket line 60 goes around the two ladder sections 53 and 54, passing from a turnover at the upper tumbler 56 down to the digging position at the lower tumbler 58. On their upper run the buckets 61 ride across supporting planar ladder surfaces 62 and 63, and on the lower run their slack may be taken up somewhat by one or more intermediate idlers; shown is an underrun bucket idler 64 on the hull 51 and an underrun bucket idler 65 supported from the upper ladder section 53. These idlers 64 and 65 help to limit slack and tension in the bucket line, among other things.

The underrun bucket idler 65 can be located within or very close to the suspension points of the adjacent ladder section 53, thereby minimizing the bending moment in that ladder section 53, which is induced by the weight of the underrun buckets 61 carried by the idler 65. This structure is not possible in conventional one-piece ladders, where the bucket idlers must be located approximately midway between the upper and lower ends of the one-piece ladder, thereby inducing the maximum bending moment. The idler 65, when located according to the present invention, contributes further to enabling reduction in the required section-size and weight of all of the swingable ladder sections. Alternately, conventional caterpillar-type idlers may be used in lieu of the wheel-type idlers 65 shown, with the same location advantages.

Each of the articulated ladder sections 53, 54 is adapted to swing pivotally relative to the hull 51 and to its adjacent ladder section. The support and relative swinging may be accomplished by means of a forward ladder suspension 66 and an after ladder suspension system 67, each of which comprises a block-and-tackle assembly and a plurality of cables 68 secured to its ladder. A headline 70 at the forward end of the hull 51 passes over a pulley 71 down to a headline winch 72, and each of the ladder hoists includes a cable 73 or 74 passing from an upper pulley of the suspension system 66 or 67 to a winch 75 or 76, located at appropriate locations on the hull 51. The forward ladder suspension system 66 is, of course, the longer, since the forward ladder 54 goes down deeper.

At the upper end of the after ladder 53, adjacent the upper tumbler 55, there may be a revolving screen 77 which receives the material that is dumped from the buckets 61 through an open end 78 and slopes down

over a tail sluice **80.** The oversized dredged barren material goes through the screen **77** and into the tail sluice **80,** with the valuable mineral-containing fraction going through the screen perforations and out to the side in a part not shown in FIG. **1** but well known in dredges. At the tail sluice **80,** the dredged mineral-barren material washes back in a well-known manner, the tailings going out the end of the tail sluice **80** and gradually building up there. Other conventional apparatus for handling the dredged material for mineral recovery or for other purposes may be employed, many such being well known in the dredge art.

In order to enable the ladders **53** and **54** to move up and down from below the hull to above it and back, a suitable well-side slot **81** is provided on the hull **51** to receive the pivot assembly **57** between the ladder sections **53** and **54.**

By making the ladder articulated, neither of the ladder sections **53** and **54** has itself to withstand all of the burden; so each ladder section **53** and **54** 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.

Broken lines **82** and **83** in FIG. **1** show, respectively, (1) how the two ladder sections **53** and **54** can be dropped lower and in line and (2) how the lower ladder section **54** can be used at a different angle in line with the upper ladder section **53.** In the solid line position, the lower ladder section **54** is dropped below the centerline continuation of the upper ladder **53.**

FIG. **2** shows a similar dredge **100** with a hull **101** and having a three-section ladder assembly with an upper ladder section **102,** an intermediate ladder section **103** and a lower ladder section **104.** The dredge **100** is capable of being used at depths even greater than those of which the FIG. **1** device is capable. It is feasible to go beyond FIG. **2** and have more than three movable articulated ladder sections. Once again, the general principle is the same. The upper ladder section **102,** while movable, does not necessarily have to move during times when both the intermediate ladder section **103** and the lower ladder section **104** swing, and the lower ladder section **104** can be swung relative to the intermediate ladder section **103,** the broken lines **105, 106,** and **107,** illustrating some of the ladder positions.

Each ladder section **102, 103,** and **104** has its suspension **112, 113,** or **114,** like the suspensions **66** and **67.** The bucket line **110** is like the bucket line **60,** but longer. There are two well-side slots **115** and **116** to accommodate the two pivot members **117** and **118.** Each suspension **112, 113, 114** has its winch **122, 123,** and **124.** The headline **120,** the rotating screen **121,** and tail sluice **125** are like the corresponding parts in FIG. **1,** and the upper tumbler **126** may rotate about the same axis as that for the pivot for the upper ladder section **102.** Operation is basically the same as for the dredge **50.**

FIGS. **3** to **13** relate to offshore dredging, where the problems brought on by waves and swells are met. In addition there are some other structural differences which are applicable to quiet-water dredges.

FIGS. **3** and **4** show an offshore dredge **130** generally similar to the dredge **50** of FIG. **2,** but having some important differences. The hull **131** and superstructure **132** support an articulated ladder having three swingable sections **133, 134,** and **135,** pivoted to each other at pivots **136** and **137,** while the after ladder **133** is pivoted to the superstructure by a pivot **138.**

In addition, however, this dredge **130** provides a fixed ladder section or ramp **140** above the after ladder **133.** The bucket line **141** continues up the ramp **140** and around an upper tumbler **142** there. This ramp or fixed ladder section **140** is never moved and enables the attainment of a higher upper level without having to increase the section thicknesses and weight of the uppermost movable ladder section **133.** As a result, of course, greater depths can be obtained with substantially the same *movable* ladder sections as in FIG. **2,** since the fixed ladder section **140** takes up a substantial portion of the total ladder length involved.

The broken line **155** shows how the three ladder sections **133, 134,** and **135** may be kept in line while being swung relative to the fixed ladder section **140.** During this swinging, the position of the upper portion of the bucket line **141** is not changed, and it still is able to dump its load into a rotating screen **156** (or other receiving apparatus) with the relationship between the bucket line **141** and the screen **156** (or other receiving apparatus) remaining unchanged. The underrun bucket line **141** goes down to a lower tumbler **143,** via idlers **144** and **145.** The idler **145** has the advantage, previously noted as to the idler **65** of FIG. **1,** of minimizing the bending moment of the ladder section **133,** by being located within or close to its suspension point. Suspensions **146, 147,** and **148** are operated by respective winches **150, 151,** and **152** to raise and lower each ladder section **133, 134,** and **135,** either all together, or separately.

The other principal differences which distinguish the FIG. **3** structure from that of FIG. **2** are those that enable the dredge of FIG. **3** to be used in offshore or ocean waters where there are swells, so that difference between the crests and troughs may be up to twenty feet or even more. It is apparent that if no attempt is made to compensate for the swelling, the dredge buckets will either come up empty most of the time or will crash into the solid bottom some of the time. In the present invention, 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 lower tumbler **143** is kept in a fixed position for any selected digging depth, in relation to the dredging face and the dredged sea bottom **153** irrespective of the water surface conditions in terms of waves and swells. The lower tumbler **143** remains at its fixed x, y position (or the x', y' position shown in broken lines) for any selected digging depth, while the ladder **133, 134, 135** traverses the lower tumbler **143** 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 **154** suspended by a cable **157** and (2) an angle indicated **158,** which are shown in FIG. **3** and, in more detail, in FIG. **10.**

FIGS. 3 and 4 illustrate the broad effect of the compensating mechanism, which is shown in more detail in FIGS. 9–13. FIG. 4 shows the dredge **130** as it is at a swell crest, and FIG. 3 shows the same dredge **130** in the swell trough. During the trough time the dredge hull **131** is closer to the bottom **153** than during the crest time; therefore during the crest the two lower ladder sections **134** and **135** are dropped to gain additional depth, as shown in FIG. **4**, the upper section **133** here remaining unchanged. However, only the lower ladder section **135** may be dropped for swells of lesser magnitude. As the water level drops again to the trough, the ladder is straightened out and may return to the common center line shown in FIG. **3.**

FIGS. **5–8** help to clarify the general aspect of this compensating action while also illustrating an alternative dredge **170** having a hull **171**, superstructure **172**, a fixed upper ramp or ladder **173** and two swingable ladder sections **174** and **175** with their suspensions **176** and **177** and articulated joint or pivot **178** and an upper pivot **179** for the section **174.**

The use of the fixed upper ramp **140** (FIG. **3**), **173** (FIG. 5), or **323** (FIG. **25**) in the invention enables either (1) a shorter length of suspended ladder **133, 134, 135** (FIG. 3) or **174, 175,** (FIG. 5), or **324** (FIG. **25**), with the ensuing advantages of having less suspended ladder weight, less required capacity in the ladder suspension and hoisting systems and a reduction in the structural requirements of certain elements of the superstructure, or (2) increasing the digging depth of existing conventional dredges by installing a fixed upper ladder ramp **140** or **173** or **323** and then utilizing an original suspended ladder **324** with its upper pivot connection relocated at a lower position, whether or not additional pivoted ladder sections **174** or **134** and **135** are added thereto.

FIG. **5** shows, in broken lines, an upper nearly horizontal stowed position of the ladder sections **174** and **175.** In solid lines it shows a lower digging position — also with the ladder sections **174** and **175** in a straight line. FIG. **6** shows, in diagrammatic form only, four positions A, B, C, and D of the ladder combination **174, 175,** always kept in a straight line — for trough conditions. These four positions correspond to different stages of digging when the dredge makes its "bite" at different levels along a digging face.

FIGS. **7** and **8** correspond to swell crest conditions of the dredge **170,** with the lower ladder section **175** inclined downwardly about its pivot **178,** by slacking its suspension **177.** Positions A, B, C, and D in FIG. **8** are the same as the same positions in FIG. **6,** with the ladder section **175** inclined to make up for the rise in level of the hull **171.** The idea, thus, is to compensate for the difference in vertical distance of the hull **171** above the bottom **153** by so dropping the lower ladder section **175** relative to the ladder section **174** that the lower tumbler **180** remains in exactly the same position as the water rises and falls.

As shown in FIG. **10,** the sounding device **154** of well-known type acts through a cable **157,** e.g., in cooperation with pulleys **149** and a weight **159,** to provide a mechanical signal indicating the change in the vertical position of the dredge hull **131** up and down as crest and trough conditions occur. This may be interpreted as the height of the hull **131** above the bottom **153** or may be taken from any predetermined point of reference. The mechanical signal from the sounding device **154** is used mechanically to vary the resistance setting of a swell potentiometer **401.** Similarly, the angle indicator **158** is set at or adjacent the pivot member **138** and acts mechanically to vary the resistance setting of a pitch potentiometer **402,** in accordance with the angle which the true horizontal makes with the nominally horizontal center line of the hull **131.** The potentiometers **401** and **402** transmit electrical signals as voltages to a swell-and-pitch correction module **403,** as shown in FIGS. **9** and 13A. The swell-and-pitch correction module **403** operates in cooperation with a Y-coordinate command module **404** having a command potentiometer **405** and an X-coordiante command module **406** having a command potentiometer **407.** The modules **403, 404,** and **406** are described below and are illustrated in FIG. 13A.

The lower tumbler **143** is initially positioned into a preselected x, y (or x', y') position by the Y-coordinate command module **404** and the X-coordinate command module **406;** these command modules **404** and **406** may be command by a winchman manually through the potentiometers **405** and **407.** For a dredge **130** like that of FIGS. **3** and **4,** the Y-coordinate command module **404** provides three signals **Y1, Y2,** and **Y3,** one to set each of the three ladder suspensions **148, 147,** and **146,** respectively, to move its ladder section **135, 134,** and **133** to the proper elevation. In a dredge like that of FIGS. **5–8,** there are only two such signals because there are only two ladder suspensions **176** and **177.** In both types of dredge there is only one signal from the X-coordinate command module **406** because that signal controls only the headline **184.**

As the dredge hull **131** begins to rise vertically on an incoming swell from the FIG. **3** position to the FIG. **4** position, the conventional automatic sounding device **154** indicates the depth of water between the dredged bottom datum **153** and the dredge hull **131.** This depth is transmitted by the cable **157** and the swell potentiometer **401** to the swell-and-pitch correction module **403** (FIG. **9**) to provide correction signals **435, 436,** and **437** respectively for the Y1, Y2, and X coordinates. A forward ladder suspension control module **470** and an intermediate ladder suspension control module **500** receive respective corrected signals **441** and **442** and issue a command signal causing respective hydraulic-system solenoid valves **160** and **161** to open (see FIG. **11**) so that respective pistons **162** and **163** in hydraulic cylinders **162*a*** and **163*a*** move to the left, and respective sheaves **164, 165** moves from position D towards position C, thus paying out lufflines **168** and **167** to the forward and intermediate ladder suspensions **148** and **147** respectively by an amount such that the lower tumbler **143** remains at its desired digging elevation, the y coordinate. Meanwhile, a headline control module **450** (FIG. **9**) receives a corrected signal **440** and issues a command signal for a hydraulic-system solenoid valve **181** to open (See FIG. **12**), moving a piston **182** in a cylinder **182*a*** to the right, and a sheave **183** moves from position E toward position F, thus taking up on a headline **184,** so that the lower tumbler **143** remains at its x digging coordinate. Thus, the x, y position of the lower tumbler **143** remains the same.

On a falling swell the sounding device **154,** the transmitting swell potentiometer **401,** and swell-and-pitch correction module **403** provide signals for reverse action of the compensating system, that is, the lufflines

168 and 167 are taken up and the headline 184 is paid out the required amount.

The forward and intermediate ladder suspension control modules 470 and 500 and the headline control module 450 issue commands for the compensation cylinders 162*a* and 163*a* and 182*a* to adjust for the variable swells. When the vertical rise and fall of the dredge hull 131 under swell condition causes the pistons 182, 162 and 163 to approach the end of their travel in or out, limit switches 185, 186 or 185*a*, 186*a* or 185*b*, 186*b*, completing the "raise" or "lower" circuit to their respective motors 187, 187*a*, 187*b* to pay out or take up lines 184, 168 or 167, as the case may be, over the travel capacity of the hydraulic cylinders 182*a*, 162*a*, and 163*a*, until the controller signal is broken. In the case of single headline 184, the practical travel capacity of the system is adequate for a headline travel for a related vertical motion of the dredge hull 131.

The swell signal is corrected by a suitable angle measuring device 158 (FIG. 10), that measures the variable angle β between the horizontal center line of the hull 131 and true horizontal, which, in itself, compensates for foreand-aft hull trim under sea conditions, further insuring the desired positioning of the lower tumbler 143 at all times. This angle is transmitted to the swell-and-pitch control module 403 by the potentiometer position indication 402.

Of the command modules 403, 404 and 406 (FIGS. 9 and 13A) the X-coordinate command module 406 is the simplest, comprising basically a voltage-to-current converter 408 and a summing amplifier 409, as shown in FIG. 13A.

The voltage-to-current converter 408 and all the other voltage-to-current converters spoken of in this specification, may be off-the-shelf items. For instance, they may each be a Foxboro 66GT or 66GC series voltage-to-current converter. These converters accept a 1 to 5 volt DC input and convert it to a proportional 10 to 50 milliampere DC output. A constant current source forming part of this converter excites a remote slide wire, such as the command potentiometer 407. 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 408. Other values, of course, can be provided. The converter 408 may contain a magnetic and transistor amplifier and be connected to a supply voltage. Since it is an off-the-shelf item, it need not be further described.

Similarly, the summing amplifier 409 and all the other summing amplifiers used here may be a Foxboro 66CT or 66CC series electronic "Consotrol" summing amplifier. These summing amplifiers are able to receive up to four 10 to 50 milliampere DC input signals and to provide a 10 to 50 milliampere 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 in this invention, 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 404 includes a voltage-to-current converter 410 like the converter 408, which takes its input from the command potentiometer 405 and which supplies, in this instance, three current repeaters 411, 412, and 413. These current repeaters, like the others used in this invention may also be off-the-shelf items, such as the Foxboro 66BT and 66BC series electronic "Consotrol" current repeaters. These repeaters receive a 10 to 50 milliampere DC input signal and produce an electrically isolated 10 to 50 milliampere DC output. They have a low input resistance of about 100 ohms and can feed an external load up to 660 ohms. 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 404 also includes two summing amplifiers 414 and 415, both connected to the current repeater 412. These summing amplifiers 414 and 415 may be off-the-shelf units identical to the summing amplifier 409 already described. Each of these summing amplifiers 414 and 415 feeds its signal to a signal characterizer 416 or 417, while the current repeater 413 feeds its signal directly to a signal characterizer 418 to produce the Y3 output 443. Each of these signal characterizers 416, 417, and 418, like others to be mentioned later, may be off-the-shelf 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 403 has two inputs, as already noted, one from the swell command potentiometer 401 operated by the sounding device 154, which feeds into a voltage-to-current converter 420, and the other from the pitch command potentiometer module 402 operated by the angle generator 158, which feeds its output to another voltage-to-current converter 421.

The voltage-to-current converter 421 feeds its current output to a current multiplier 422, which is supplied by a constant current source 423 and to another current multiplier 424, fed by a constant current source 425, to achieve two different multiplied outputs. These current multipliers may also be off-the-shelf items, such as the Foxoboro 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 sources 423, 425 used for these multipliers may each be an off-the-shelf 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 transistorized amplifier and other features. Here they are used only for reliable current sources of a standard current to give a fixed multiplier.

Thus, the current multipliers 422 and 424 are used to supply two independent products originating from the same signal. They may be supplying substantially the same product or they may be supplying a different

product, depending on the setting of the current sources **423** and **425**.

The swell-and-pitch correction module **403** also includes three signal characterizers **426, 427** and **428** (like the signal characterizers **416, 417, 418**). It also includes a pair of summing amplifiers **430** and **431** and three current multipliers **432, 433** and **434**. The current repeater **411** of the Y-coordinate command module **404** is connected to the signal characterizer, **426** and **427** of the swell-and-pitch correction module **403**. The current multiplier **422** and the voltage to current converter **420** are connected to the summing amplifier **430**, and the voltage-to-current converter **420** is also connected to the summing amplifier **431**, to which is also connected the output from the current multiplier **424**. The output from the summing amplifier **430** is connected to the current multipliers **432** and **433**. The signal characterizer **426** is also connected to the current multiplier **432**, so that the output (or correction signal) **435** from the current multiplier **432** is proportional to the product of the multiplication of the outputs of the signal characterizer **426** and the summing amplifier **430**. The summing amplifier **431** and the signal characterizer **427** are connected to a current multiplier **434**, whose output or correction signal **436** is proportional to the product of those two inputs.

The current repeater **412** of the Y-coordinate command module **404** is connected to the summing amplifiers **414** and **415**, and the current multiplier **434** feeds its output or correction signal **437** to the summing amplifier **415**. The output from the summing amplifier **415** goes to the signal characterizer **417**, which thereupon produces the Y2 output **442**.

The current repeater **412** also feeds its signal to a signal characterizer **428** which feeds its output to the current multiplier **433**, and the output from the current multiplier **433** is fed to the summing amplifier **409**, which is otherwise fed directly by the voltage-to-current converter **408** of the X-command module **406**. This produces the signal output **440** of the X-command module **406**.

The current multiplier **432** is fed to the summing amplifier **414**, as is the signal from the current repeater **412**, and the sum of these is then fed to the signal characterizer **416** to produce the Y1 output **441**.

What has been described so far, then, results in a single output **440** from the X-command module and three outputs **441, 442**, and **443** from the Y-coordinate command module, and this concludes the description of FIG. **13A**.

The output **440** from the X-coordinate command module is fed to the X-coordinate control module **450**. The output **440** is fed directly to a motor operated setter **451** of the control module **450** (FIG. **13B**). This, like the other motor operated setters to be described, may also be an off-the-shelf item, such as, the Leeds and Northrup Company's M-line, model C, motor operated setter. This motor operated setter **451** tracks the signal **440** and positions a retransmitting slide wire which is a set point potentiometer **452** for a set point-/auto-manual station **453**, the set point potentiometer **452** being fed directly to the set point/auto-manual station **453**. This, like the other set point/auto-manual stations to be described, may also be an off-the-shelf 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 station **453** compares the set point potentiometer **452** with the output **454** of a position feedback summing amplifier **455** (see FIG. **13C**), and the unbalance between these two signals becomes an error signal **456** that is proportional in magnitude and polarity to the unbalance.

The output **456** is fed directly to a position adjuster **460** (FIG. **13C**). This, like the other position adjusters to be described, may also be an off-the-shelf 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 signal **456** in this instance) from the set point unit **453** (See FIG. **13B**) and, through an amplifier, energizes 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 **440** is used here as the set point, and the position feedbacks are set mechanically through position-feedback potentiometers **461** and **462**.

With reference to FIGS. **11, 12, 13B**, and **13C**, the position-feedback potentiometer **461** feeds its signal to a voltage-to-current converter **463** (like the converter **408**), and the position feedback potentiometer **462** feeds its signal to a voltage-to-current converter **464** of the same type. The outputs from the converters **463** and **464** are fed to the summing amplifier **455**, which feeds its output **454** into the set point/auto-manual station **453** that provides the error signal **456** to the position adjuster **460**. The position adjuster **460** has two output cables **465** and **466**, the cable **465** feeding raise-lower control power to the solenoid valve **160** and a pump **188***a* for the compensating system hydraulic cylinder **162***a*, and the cable **466** feeding raise-lower control power to the motor **187** for the headline winch **189**.

The output **441** from the Y-coordinate command module **404** is fed to a control module **470**. The output **441** is fed directly to a motor-operated setter **471** (FIG. **13B**), like the motor-operated setter **451**. The motor operated setter **471**, tracks the signal **441** and positions a retransmitting slide wire set point potentiometer **472** feeding directly to a set point/auto-manual station **473**. The set point/auto-manual station **473** compares the set point potentiometer **472**, with the output **474** of a voltage-to-current converter **475**, and the unbalance between these two signals becomes an error signal **476** that is proportional in magnitude and polarity to the unbalance. The output or error signal **476** is fed directly to a position adjuster **480**. The control module **470** also has a position-feedback potentiometer **481** sending a signal to the voltage-to-current converter **475** which provides the base signal for the position adjuster **480**, from which outputs **482** and **483** are fed to the solenoid valve **160** and pump **188***a* forward ladder hoist motor **187***a* for the winch **152**.

The Y-coordinate command module **404** sends its second or Y2 signal **442** to a control module **500**. The output **442** is fed directly to a motor operated setter **501**, which tracks the signal **442** and positions a retransmitting slide wire set point potentiometer **502**, which is fed directly to a set point/auto-manual station **503**. The set point/auto-manual station **503** compares the set point potentiometer **502**, with the output **504** of

a position feedback summing amplifier **505**, and the unbalance between these two signals becomes an error signal **506** that is proportional in magnitude and polarity to the unbalance. The output or error signal **506** is fed directly to a position adjuster **510** like those previously described. The signal **442** is used as the set point signal, and the unit's position feedback is controlled by two feedback potentiometers **511** and **512**, respectively feeding voltage-to current converters **513** and **514**, the outputs of which are added by the summing amplifier **505**. The outputs **515** and **516** from the position adjuster **510** is then used to control the solenoid valve **161** and hydraulic pump **188***b* and the intermediate ladder hoist motor **187***b* for the winch **151**.

The third output signal from the Y-coordinate command module **404** is the signal **443**, which is fed to a control module **520**. Here again, the output **443** is fed directly to a motor operated setter **521** which tracks the signal **443**, and positions a retransmitting slide wire set point potentiometer **522**. The set point potentiometer **552**, is fed directly to a set point/auto-manual station **523** which compares the set point potentiometer **522**, with the output **524** of a voltage-to-current converter **525**, and the unbalance between these two signals becomes the error signal **526** that is proportional in magnitude and polarity to the unbalance and is fed directly to a position adjuster **530**. The position feedback is set by a feedback potentiometer **531** feeding its signal to the voltage-to-current converter **525**. A single output **532** from the position adjuster **530** is connected to the after ladder hoist motor **190** for the winch **150**.

As shown in FIGS. **9** and **11**, each of the three ladder suspensions shown in FIG. **11** receives feedback from its command potentiometers, each of which is related to the position of the devices controlled thereby. Thus, the control module **470** for the forward ladder **135** receives feedback from its position-indicating potentiometer **481** that is located adjacent a pulley **191** for the suspension line **148**. The intermediate control module **500** for the ladder **134** receives feedback from the potentiometer **511** that indicates the position of the traveling sheave **165** and from the potentiometer **512** that indicates the position of the winch drum **151**. The control module **520** for the after ladder **133** receives feedback from its potentiometer **531** that indicates the position of the winch drum **150**.

Similarly, as shown in FIGS. **9** and **12**, the command module **450** for the headline **184** receives feedback from the command potentiometer **461** indicating the position of the traveling sheave **183** and from the potentiometer **462** indicating the position of the winch drum **189**.

In operation, the command signal for the Y-coordinate command module **404**, provided by the potentiometer **405**, which is calibrated in feet, is adjusted by the dredge winchman. The slidewire excitation signal built into the voltage-to-current converter **410** provides the excitation for the potentiometer **405**, and the output signal of the voltage-to-current converter **410** drives the three current repeaters **411**, **412**, and **413**. The output from the current repeater **411** drives the two signal characterizers **426** and **427** in the swell-and-pitch correction module **403**. The output from the current repeater **412** drives the two summing amplifiers **414** and **415**, and the signal characterizer **428** in the swell-and-pitch correction module **403**. The output of the current repeater **413** drives the signal characterizer **418**, whose output signal **443** is the Y3 output **443** used to drive the after ladder suspension control module **520**.

The two summing amplifiers **414** and **415** provide the sum of Y plus Y1′ and Y2′. Their output drives the signal characterizers **416** and **417** which respectively provide the Y1 and Y2 output signals **441** and **442** that drive the forward and intermediate ladder suspension control modules **470** and **500** respectively.

The X-coordinate command module **406** input signal is fed to the voltage-to-current converter **408** and from there to the summing amplifier **409**, whose other input signal comes from the swell-and-pitch correction module **403**, and the output **440** therefrom drives the headline control module **450**.

The swell-and-pitch correction module **403** receives four signals; first and second are from the respective current repeaters **411** and **412** of the Y-coordinate command module **404**; third, the pitch from the potentiometer **402** that is positioned by the angle indicator **158**; and fourth, the swell from the potentiometer **401** which is positioned by the sounding device **154**. The pitch signal is proportional to the tangent of angle β, and is sent to the two multiplier amplifiers **422** and **424**. The second input to each of the multiplier amplifiers **422** and **424** is the constant signal provided respectively, by the two current sources **423** and **425** which represent one leg of a triangle. The outputs of the two multiplier amplifiers **422** and **424** are equal to the Y1′ and Y2′ pitch component, and these two components are inputs to their respective summing amplifiers **430** and **431**.

The swell signal from the voltage-to-current converter **420** is proportional to the vertical distance that the bottom of the dredge hull **131** lies above the trough of the swell, and this signal is the other input to the two summing amplifiers **430** and **431**. The output of the summing amplifiers **430** and **431** are the values of the swell pitch components Y1′ and Y2′. The swell pitch components, outputs of the summing amplifiers **430** and **431** are corrected according to the depth the dredge is digging by the multiplier amplifiers **432** and **434**, whose second inputs are from the signal characterizers **426** and **427** which are driven by a Y coordinate signal. The outputs **435** and **436** of the multiplier amplifiers **432** and **434** are then equal to the required Y1′ and Y2′ coordinate correction, which are inputs to the Y-coordinate command module **404**.

The X′ coordinate is computed by the Y1′ output from the summing amplifier **430** as one input to multiplier amplifier **433**, and the second input is the output from the signal characterizer **428**, which is driven by a Y coordinate signal. The output **437** of X′ coordinate multiplier amplifier **433** is the correction input to the X-coordinate command module **406**.

The swell and pitch signal may be adjusted and calibrated so that the final output signals **440**, **441**, **442**, and **443** are all positive.

The set point of the position adjuster **480** is adjusted by the input signal **441** from the Y-coordinate command module **404**. This set point signal **441** is balanced against the actual feedback signal **474** from the potentiometer **481** and the voltage to current converter **475**, which represent the actual Y-coordinate of the lower tumbler **143**. The resultant error signal **476**, proportional to the deviation and direction of the lower tumbler **143** from the set point, is transmitted to the posi-

tion adjuster **480.** The output of the position adjuster **480** is a contact closure of one of the relays **484** and **485.** The relay **484** is energized when the value is greater than the set point; the relay **485** is energized when the value is less than the set point. Positioning of the lower tumbler **143** is accomplished by closing either the "raise" relay **485** or the "lower" relay **484** to energize the compensating hydraulic system valve **160** and the ladder hoist motor **187***a* if the hydraulic cylinder reaches maximum travel to the position called for by the control unit **470.** At this "balanced" position, neither relay **484** nor **485** is closed. The position controller **480** has auto, manual "raise" and manual "lower" pushbuttons; deviation and position meters; and adjustable proportion reset and rate actions.

The intermediate ladder suspension and the headline control modules **500** and **450** are similar to the forward ladder suspension control module **470** except for the feedback position signals, which come from the traveling sheave **165** and the hoist drum **151.** The hydraulic cylinder feedback potentiometer **511** feeds the voltage-to-current converter **513**; and the winch drum potentiometer **512** feeds the voltage-to-current converter **514,** and these output signals from the converters **513** and **514** are added in their respective summing amplifier **505.** The output of the summing amplifier **505** is the position feedback signal **504** to the respective set point-/auto-manual station **503.** Similarly, the position of the sheave **183** is noted by the potentiometer **461,** and the position of the winch drum **189** is noted by the potentiometer **462,** and their signals are summed and reported to the set point/auto-manual station **453.**

The after ladder suspension control module **520** is simpler than the forward ladder suspension control module **470.** The control "raise" or "lower" signal energizes the ladder hoist motor **190** only, and the position feedback signal is from the potentiometer **531** for the winch drum **150.**

For raising the ladder above water for maintenance and repairs to the lower tumbler **143,** bucket idlers, or idlers, bucket line, etc., or for other reasons, manual control of the ladder hoists and headline winch is employed, with the automatic compensating systems cut out.

The sea dredge of FIGS. **5–8,** employing two lower articulated ladder sections **174** and **175** have suspension systems with analogous compensating arrangements. For this particular example of a deep digging sea dredge, swells up to about twenty feet can be compensated for.

FIG. **14** shows a dredge **250** having a hull **251,** a superstructure **252,** two articulated ladder sections **253** and **254,** and a fixed ladder section **255.** In this instance, the fixed ladder section **255** is not arranged to support the same bucket line as the ladder sections **253** and **254**; instead the dredged material is transferred from a lower bucket line **256** that did the digging to an upper bucket line **257** on the upper fixed ladder section **255.** The lower bucket line **256** thus drops its load, as it rounds its upper tumbler **258,** into the lower bucket line **257** which is coming up from its lower tumbler **259.** The load is then carried over the upper tumbler **260** of the upper bucket line **257** and spilled into a rotating screen **261,** or other suitable treatment or receiving device.

The combination in FIG. **14** of two independent tandem bucket line systems **256** and **257** employing a fixed ladder **255** for the upper bucket line **257** has the following additional advantages:

1. the upper tumbler **258** for the digging bucket line **256** and its drive are at a lower elevation, thus materially shortening the length of the digging bucket line **256**;

2. the upper or second-stage ladder section **255** is not subjected to a long bucket line dead load nor to digging loads, therefore it can be of relatively light construction throughout;

3. the dredge **250** can have a lower vertical center of gravity, since the upper tumbler **258** for the digging bucket line **256** and its drive machinery can be located at a substantially lower height than for a conventional single bucket line system;

4. further contributing to a lower center of gravity and favorable economics is the lighter superstructure **252** required for carrying the relatively light dead and live loads of the second-stage elevating system **255.**

FIGS. **15** to **20** show some important details of a dredge like those of FIGS. **5** and **7** in having a fixed upper ramp section **173** of the ladder, with a ladder section **174** pivoted below it and articulated to a lower ladder section **175.** An upper tumbler **270** is secured to a shaft **271,** on which is mounted a pair of pinion gears **272, 273** that are driven by pinion gears **274, 275** to drive the upper tumbler and thereby the bucket line **280,** which is not shown in FIGS. **15–19.** The fixed ramp **173** supports a plurality of rollers **276,** as do the articulated ladder sections **174** and **175** over which the bucket line **280** moves. The upper end of the ramp **173** includes a frame section **277** that diverges out beyond the bucket line **280** and is secured to both the superstructure **278** and the hull of the floating dredge. The pivot shaft **179** supported by the superstructure **278** and independent of the fixed ramp **173** supports the clevised upper end **281** of the upper section **174** of the articulated portion of the ladder; similarly, the lower end of the upper section **174** supports the shaft **178** on which the clevised upper end **282** of the lower section **175** of the articulated ladder is pivotally supported. The shafts **178** and **179** may, as an option, carry flanged guide rollers **283** and **284,** and there is a lower tumbler **285** at the lower end of the ladder portion **175.**

FIG. **18** also shows an alternate form of lower ladder end **279** wherein the top surface **289** of the ladder end **279** is cambered, while the bottom surface **292** is straight. This feature provides (1) for several additional feed of digging depth, as compared with a conventionally shaped ladder end in a ladder of the same overall length, and (2) for additional clearance between the bottom surface **292** of the ladder end **279** and the underrun buckets aft of the lower tumbler **285,** — a desirable feature when digging on a hard bottom where the underrun buckets tend to rub on the bottom surface of the ladder end near the lower tumbler, thereby causing wear and damage to both the buckets and the underside of the ladder end.

FIG. **16** shows one important effect of the use of the fixed ramp **173.** This is its assurance that the bucket pin pitch line **280***a* engages and leaves the upper tumbler **270** at the same angle — tangent at all times to the pitch circle **270a** of the upper tumbler **270.** FIG. **20** shows another advantage that can be used: the bucket line **280,** in conjunction with a deck bucket idler **286** is able to maintain a constant minimum clearance distance between the discharging bucket lips **287** and the

receiving chute lip **288** for all the vertical positions of the digging ladder, thus reducing to a minimum the spillage and loss of the dredged material. Further, a plurality of generally vertical inclined grizzly bars **290** may be used in conjunction with a save-all chute **291** to recover additional dredged material not received by the chute **288.** Further for reasons that dredge designers will appreciate, the receiving chute **288** location is facilitated by the introduction of a fixed ramp **173,** in that the height of both the upper tumbler and receiving chute can be raised, by the introduction of a fixed ramp without increasing the swingable ladder length, to improve the efficiency of the gravity flow system of the treatment plant and/or to place the plant tailings further astern of the dredge via the tail sluices shown as **80** and **125** respectively of FIGS. **1** and **2.**

The articulated ladder with the fixed-ramp upper ladder section **173** may be used for either inland waters or sea dredges, thus enabling the bucket line **280** to lead at all times tangent to the pitch circle of the upper tumbler **270,** which is coaxial with the upper tumbler shaft **271.** This very desirable feature has not been heretofore satisfactorily attainable, especially in the case of sea dredges. Moreover, none of the digging forces that act on the lower tumbler **285** pass beyond the upper end pivot connection **179** of the suspended swingable ladder section **174;** thus pivot connection is structurally independent of the fixed ramp upper ladder section **173,** so that the upper tumbler **220** and the drive machinery are positively protected from all digging forces. In conjunction with the deck bucket idler **286,** a constant minimum clearance distance is maintained between the discharging bucket lips **287** and the receiving chute lip **288** for all vertical positions of the digging ladder **174, 175,** thereby reducing spillage and loss of dredged material to the minimum, and even this is salvaged by the grizzly bars **290** and save-all chute **291.**

Another significant feature of the foregoing arrangement is that the swingable ladder can be lowered to a greater angle of inclination. Thus, additional digging depth can be had with a given length of swingable ladder; this has not been possible with the conventional dredges hitherto available.

FIG. **25** shows a dredge **320** having an hull **321** and superstructure **322** supporting a fixed upper ladder ramp **323** and a single swingable ladder section **324,** carrying a bucket line **325.** There is an upper tumbler **326** at the top of the ramp **323** and a lower tumbler **327** at the lower end of the swingable ladder section **324.** A suspension system **328** enables the raising and the lowering of the ladder section **324.** The structure has some of the advantages just described, in comparison with conventional dredges, though it lacks many of the advantages of the system of FIG. **5.** This dredge may be used for either inland waters or in the sea, and can be provided with the swell compensation system previously applied to only one ladder section and to the head line.

FIGS. **21** to **24** 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 coplanar but converge together from their upper pulley blocks **307, 308** to a structure **310** supporting lower pulleys **311** and **312.** The structure **310** is secured to the ladder section **301** by suspension rods **313** and **314.** As shown in FIG. **21,** the angle at which the lines **305** and **306** converge widens as the lines are shortened and the structure **310** 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 or 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.

To those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the description herein are purely illustrative and are not intended to be in any sense limiting.

We claim:

1. A floating deep-digging dredge, including in combination,

a hull,

superstructure supported on said hull,

an articulated ladder comprising a plurality of sections pivoted together for relative swinging movement in a vertical plane only and including

an upper tumbler at the top of the ladder,

an upper swingable ladder section having a main pivot adjacent its upper end supported by said superstructure, and

a lower swingable ladder section having a clevised upper end with clevis arms supporting a shaft and pivoted thereby to the section above it at a lower end lying between the clevis arms, said lower ladder section having a lower tumbler at its lower extremity.

a bucket-line guide roller supported by said shaft and thereby at the pivot line of the upper and lower swingable sections,

a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and meeting and leaving said bucket-line guide roller tangent thereto and supported by said ladder, said bucket-line guide roller and clevis structure enabling maximum downward swinging of said lower section relative to said upper section while maintaining the bucket line in proper alignment with said ladder,

a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable, and

winch means for said cable supported by said hull.

2. The dredge of claim **1** wherein there are at least three swingable sections successively pivoted to each other for relative swinging movement in a vertical plane only as well as being pivoted to said superstructure at the upper end of the upper section thereof, each pivoted connection having a clevis connection as re-

cited with a bucket-line guide roller sup-ported on the pivot line thereof.

3. The dredge of claim 1 wherein the lower end of said swingable lower ladder section is suspended by two sets of block-and-tackle suspensions lying in the same plane but inclined to each other set at acute angles symmetrical about the center line of the dredge and of the multiple section ladder.

4. A floating deep-digging dredge, including in combination:
a hull,
superstructure supported on said hull,
an articulated ladder comprising a plurality of sections pivoted together for relative swinging movement in a vertical plane only and including
an upper driving tumbler supported by said superstructure near the top of the ladder,
an upper swingable ladder section having a main pivot adjacent its upper end supported by said superstructure, at a point below and near said upper tumbler
a lower swingable ladder section pivoted to the section above it and having a lower tumbler at its lower extremity,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable, and
winch means for said cable supported by said hull.

5. A floating deep-digging dredge, including in combination,
a hull,
superstructure supported on said hull,
an articulated ladder comprising a plurality of sections pivoted together for relative swinging movement in a vertical plane only and including
an upper tumbler at the top of the ladder,
an upper swingable ladder section having a main pivot adjacent its upper end supported by said superstructure, and
a lower swingable ladder section pivoted to the section above it and having a lower tumbler at its lower extremity,
said ladder having a fixed uppermost section, supported by said superstructure, said superstructure also supporting said upper tumbler,
said upper swingable ladder section being pivoted on said superstructure below and independent from said fixed uppermost section, for swinging movement relative to said fixed section,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable, and
winch means for said cable supported by said hull.

6. The dredge of claim 5 wherein said fixed uppermost ladder section is located and arranged to provide at all times a constant tangent alignment of the bucket line leading to the pitch circle of the upper tumbler and coaxial with a shaft which supports the upper tumbler.

7. A floating deep-digging dredge, including in combination,
a hull,
superstructure supported on said hull,
an articulated ladder comprising two swingable ladder sections pivoted to each other for relative swinging movement in a vertical plane only and including
an upper driving tumbler supported by the superstructure near and separate from the top of the ladder,
the upper ladder section being pivoted at its upper end directly to said superstructure independently of the upper driving tumbler, and
a lower swingable ladder section pivoted to said upper ladder section and having a lower tumbler at its lower extremity,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable, and
winch means for said cable supported by said hull.

8. A floating deep-digging dredge, including in combination,
a hull,
superstructure supported on said hull,
an articulated ladder comprising
a fixed uppermost ladder section and
at least one swingable ladder section pivoted at its upper end to said superstructure at an uppermost pivot for swinging movement relative to said fixed section in a vertical plane only, said uppermost pivot being supported independently of said fixed ladder section,
an upper tumbler at the top of said ladder,
a lower tumbler at the lower extremity of said ladder,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
at least one block-and-tackle suspension supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable, and
winch means for said cable supported by said hull.

9. A floating deep-digging dredge, including in combination,
a hull,
superstructure supported on said hull,
an articulated ladder comprising a plurality of sections pivoted together for relative swinging movement in a vertical plane only and including
an upper tumbler at the top of the ladder,
an upper swingable ladder section having a main pivot adjacent its upper end supported by said superstructure, and
a lower swingable ladder section pivoted to the section above it and having a lower tumbler at its lower extremity,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being con-

nected to the lower end of a swingable ladder section for support thereof and having a cable,
winch means for said cable supported by said hull,
sounding means for determining instantaneously the height of the hull above the bottom of the water on which the hull is floating,
depth signal means actuated by said sounding means,
angle sensing means for determining, instantaneously the angle which the true horizontal makes with the nominally horizontal center line of said hull,
angle signal means actuated by said angle sensing means, and
control means receiving said depth signal and said angle signal means and controlling the suspension length of at least said lower ladder section and accommodating it to swells in the water level on which the hull floats.

10. The dredge of claim **9** having
a headline extending from shore or sea bottom to said dredge,
a headline winch for varying the length of said headline, and
a control circuit actuated by said control means for controlling the instantaneous length of said headline during swells.

11. A floating deep-digging dredge, including in combination,
a hull,
superstructure supported on said hull,
an articulated ladder comprising a plurality of sections pivoted together for relative swinging movement in a vertical plane only and including
an upper tumbler at the top of the ladder,
an upper swingable ladder section having a main pivot adjacent its upper end supported by said superstructure, and
a lower swingable ladder section pivoted to the section above it and having a lower tumbler at its lower extremity,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable,
winch means for said cable supported by said hull,
sounding means for indicating instantaneously the height of the hull above the bottom of the water on which the hull is floating,
a first command potentiometer actuated by said sounding means,
angle sensing means for indicating instantaneously the angle which the true horizontal makes with the nominally horizontal center line of said hull,
a second command potentiometer actuated by said angle sensing means,
said winch means comprising a separate luffline winch for each said suspension,
a headline extending from shore or sea bottom to said dredge,
a headline winch for varying the length of said headline,
a third command potentiometer for setting a nominal position of said headline winch,
additional command potentiometers, one for setting a nominal position for each said luffline winch, and
control means connected to all of said command potentiometers and transmitting the settings of said third and additional command potentiometers to their said winches by a series of outputs, said control means having means for superimposing on said outputs the effects of said first and second command potentiometers,
so that the nominal positions of said headline winch and said luffline winches are kept changing to actual positions varying from said nominal positions by amounts such as are needed to keep the position of said lower tumbler substantially constant.

12. The dredge of claim **11** wherein some of the lufflines have associated with them respective hydraulic cylinders and pistons, said pistons being connected to a translatable sheave, said control means also determining both a nominal position and actual positions for said piston, as determined by the superposition of the command signals.

13. The dredge of claim **12** having a feedback potentiometer for each winch and each hydraulic piston to provide a base signal at the nominal position thereof, said control means correcting said base signal by an error signal obtained from said first and second command potentiometers.

14. A floating deep-digging dredge having a hull and a superstructure with a ladder pivotally supported by said superstructure and
a digging bucket line passing around an upper driving tumbler supported by the superstructure with the upper pivot for the ladder separately supported by the superstructure and a lower tumbler on the lower end of the ladder and supported by said ladder, characterized by
the ladder comprising a plurality of articulated sections pivoted together for relative swinging movement in a vertical plane only,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable, and
winch means for said cable supported by said hull,
the lower end of at least the lowermost ladder section being suspended by two sets of block-and-tackle suspensions lying in the same plane but inclined to each other set at acute angles symmetrical about the center line of the dredge and of the multiple section ladder.

15. A floating deep-digging dredge having a hull and a superstructure with a ladder pivotally supported by said superstructure and
a digging bucket line passing around an upper tumbler-coaxial with the pivot for the ladder and a lower tumbler on the lower end of the ladder and on both sides of said ladder and supported by said ladder, characterized by
the ladder comprising a plurality of articulated sections pivoted together for relative swinging movement in a vertical plane only,
a plurality of block-and-tackle suspensions supported by said superstructure, each suspension being connected to the lower end of a swingable ladder section for support thereof and having a cable,
winch means for said cable supported by said hull,
sounding means for determining instantaneously the height of the hull above the bottom of the water on which the hull is floating,

depth signal means actuated by said sounding means,
angle sensing means for determining, instantaneously the angle which the true horizontal makes with the nominally horizontal center line of the hull,
angle signal means actuated by said angle sensing means, and
control means receiving said depth signal and said angle signal means and controlling the suspension length of at least said lower ladder section and accommodating it to swells in the water level on which the hull floats.

16. The dredge of claim **15** having
a headline extending from shore or sea bottom to said dredge,
a headline winch for varying the length of said headline, and
means actuated by said control means for controlling the instantaneous length of said headline during swells.

17. A floating deep-digging dredge having a hull and superstructure supported thereon, including in combination
an articulated ladder comprising a fixed uppermost section supported by said superstructure and at least one lower section pivotally supported by said superstructure below and independent from the lower end of said fixed section and in alignment therewith, for relative swinging movement in a vertical plane only,
an upper tumbler supported by said superstructure at the top of the ladder,
a lower tumbler at the lower extremity of said ladder supported by a said lower section,
a digging bucket line passing around both said upper and lower tumbler and on both sides of said ladder and supported by said ladder,
block-and-tackle suspension means supported by said superstructure and connected to the lower end of each said lower section for support thereof and having a cable, and
winch means for each said cable, supported by said hull.

18. The dredge of claim **17** in which there is a single swingable ladder section, carrying said lower tumbler.

19. The dredge of claim **17** wherein there are two swingable lower ladder sections pivoted to each other, the upper of these lower ladder sections being pivoted at its upper end to said superstructure.

20. The dredge of claim **17** wherein there are at least three swingable lower ladder sections successively pivoted to each other as well as being pivoted to said superstructure at the upper end of the upper section thereof.

21. A floating deep-digging dredge, including in combination with a hull and a superstructure supported thereon:
a fixed uppermost ladder section supported by said superstructure,
a swingable ladder portion pivoted at its upper end to said superstructure for relative swinging movement of said swingable ladder portion relative to said fixed ladder section in a vertical plane only, said pivot being supported independently of said fixed ladder section and offset from its axis,
said swingable ladder portion comprising at least one ladder section and having an upper tumbler supported by said superstructure co-axial with the pivot of the swingable ladder portion and having a lower tumbler at its lower end,
a continuous digging bucket line passing around both said upper and lower tumbler and on both sides of said swingable ladder portions and supported thereby,
block-and-tackle suspension means supported by said superstructure and connected to the lower end of each section of said swingable ladder portion for support thereof, each unit thereof having a cable,
winch means for said cable supported by said hull,
a continuous transfer and delivery bucket line supported by said fixed uppermost ladder section, to which said digging bucket line transfers its load as it passes over said upper tumbler, and
means for receiving the load from said transfer and delivery bucket line as it passes over the top of said fixed uppermost ladder section, at a constant angle.

22. The dredge of claim **21** wherein said means for receiving includes inclined grizzly bars and a secondary receiving chute.

23. The dredge of claim **21** wherein said swingable ladder portion comprises two sections pivoted to each other, the upper ladder section being the one pivoted at its upper end to said superstructure.

24. The dredge of claim **21** wherein said swingable ladder portion comprises three sections successively pivoted to each other as well as being pivoted to said superstructure at the upper end of the upper section thereof.

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

26. The dredge of claim **25** having
a headline extending from shore or sea bottom to said dredge,
a headline winch for varying the length of said headline, and
a control circuit actuated by said control means for controlling the instantaneous length of said headline during swells.

27. The dredge of claim **25** wherein
said depth signal means comprises a first command potentiometer actuated by said sounding means, and

said angle signal means comprises a second command potentiometer actuated by said angle sensing means,

said winch means comprising a separate luffline winch for each said suspension,

a headline extending from shore or sea bottom to said dredge,

a headline winch for varying the length of said headline,

a third command potentiometer for setting a nominal position of said headline winch,

additional command potentiometers, one for setting a nominal position for each said luffline winch,

control means connected to all of said command potentiometers and transmitting the settings of said third and additional command potentiometers to their said winches by a series of outputs, said control means having means for superimposing on said outputs the effects of said first and second command potentiometers,

so that the nominal positions of said headline winch and said luffline winches are kept changing to actual positions varying from said nominal positions by amounts such as are needed to keep the position of said excavating means substantially constant.

28. The dredge of claim **27** wherein some of the luffflines have associated with them respective hydraulic cylinders and pistons, said pistons being connected to a translatable sheave, said control means also determining both a nominal position and actual positions for said piston, as determined by the superposition of the command signals.

29. The dredge of claim **28** having a feedback potentiometer for each winch and each hydraulic piston to provide a base signal at the nominal position thereof, said control means correcting said base signal by an error signal obtained from said first and second command potentiometers.

30. A floating deep-digging dredge having a hull and a superstructure with a ladder pivotally supported for relative swinging movement in a vertical plane only, by said hull and excavating means on the lower end of the ladder, characterized by

the ladder comprising a plurality of articulated sections pivoted together for swinging movement in said vertical plane,

block-and-tackle suspension means for the ladder supported by said superstructure and connected to the lower end of at least one swingable ladder section for support thereof and having a cable,

winch means for said cable supported by said hull,

means supported by said hull independently of said excavating means and connected to said winch means for rotation of said winch means for controlling the suspension lengths of said ladder, and

means supported by said hull for moving said hull horizontally fore and aft in synchronization with said means for controlling the suspension lengths of said ladder, for accommodating said ladder vertically and horizontally to swells in the water level on which the hull floats to keep the position of said excavating means relative to the sea bottom and dredging face substantially constant.

* * * * *