United States Patent

Mott et al.

[15] **3,680,342**

[45] **Aug. 1, 1972**

[54] **APPARATUS FOR LAYING PIPELINES**

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[73] Assignee: **Fluor Ocean Services, Inc.,** Houston, Tex.

[22] Filed: **Jan. 26, 1970**

[21] Appl. No.: **5,842**

[52] **U.S. Cl.** **72/161,** 61/72.1, 61/72.3, 226/172, 72/166, 72/199

[51] **Int. Cl.** **B21d 3/02**

[58] **Field of Search** 72/160, 161, 163; 61/72.1, 61/72.3; 226/172, 171; 254/134; 29/429

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Primary Examiner—Milton S. Mehr
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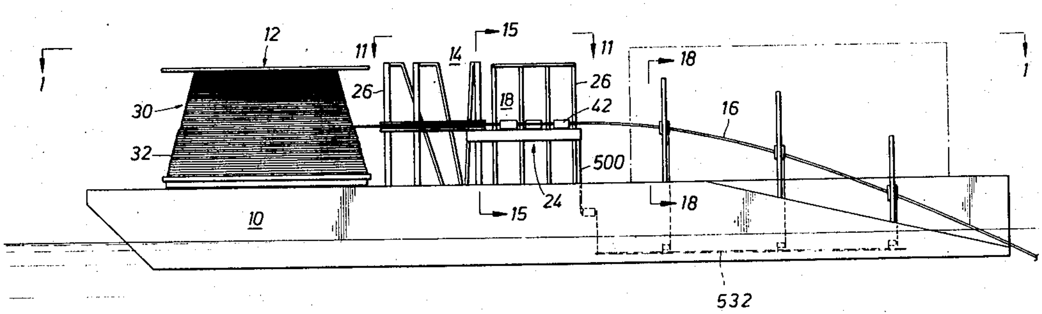
[57] **ABSTRACT**

An apparatus for laying a pipeline from a barge-mounted reel including compound-bending means, tensioning means and vertical support means. Each means preferably has an endless chain composed of blocks linked together by connecting pins. The pins also support high-load carrying rollers. The rollers ride both on relatively stiff tracks and on relatively flexible tracks which are supported by hydraulically-controlled rods operable to cause the flexible tracks to assume a desired curvature for imparting to the pipe. In the tensioning means, two such moving chains are oppositely positioned to directly engage opposite sides of a generally rectilinear portion of said pipe, thereby exerting a series of longitudinally-spaced, continuously-effective tensioning forces in the pipe. The apparatus further includes hydraulically-operated stanchions for selectively and adjustably supporting said pipeline in a vertical plane to allow the pipe to enter a body of water at a desired vertical inclination.

39 Claims, 18 Drawing Figures



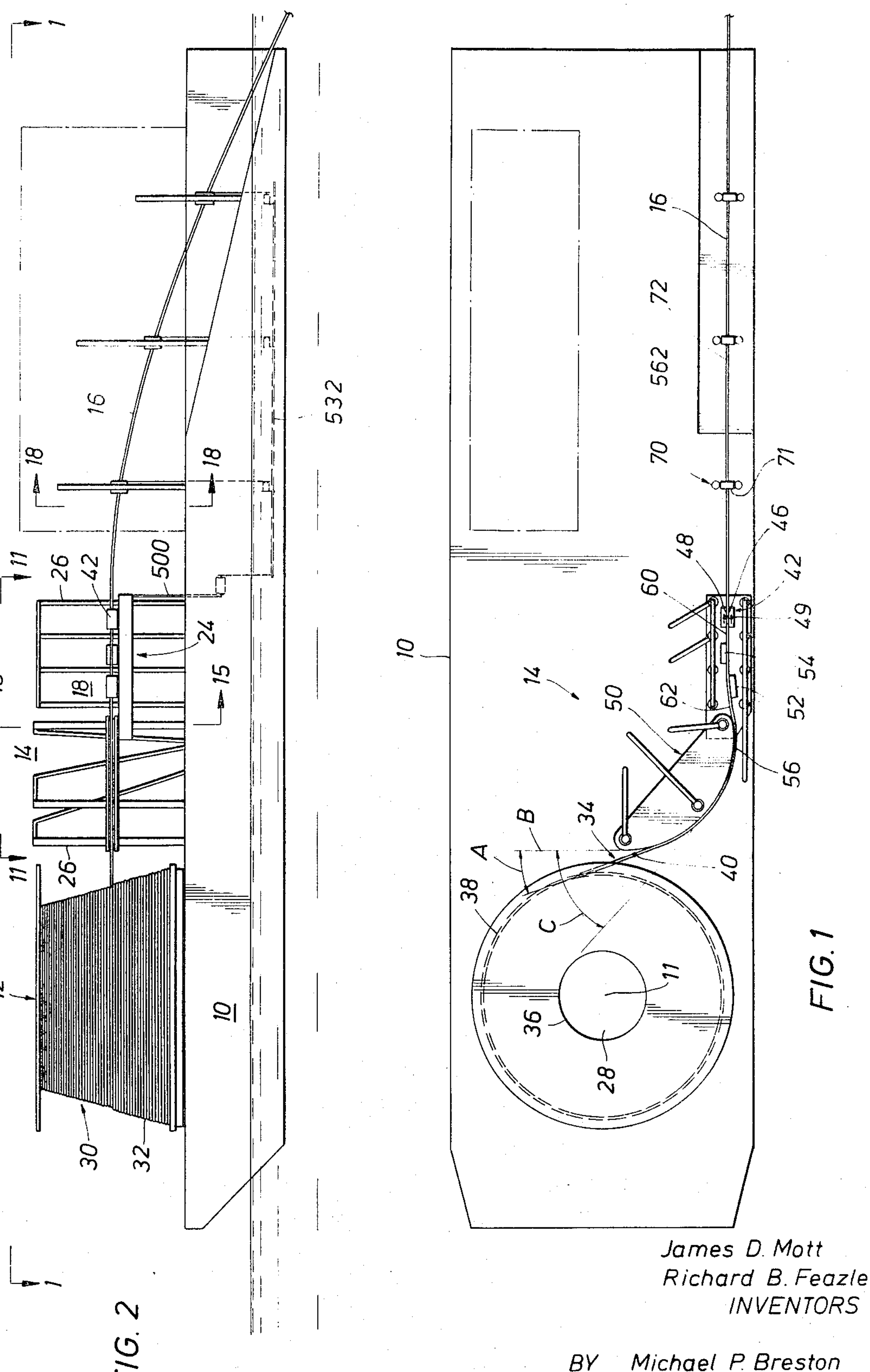


FIG. 2

FIG. 1

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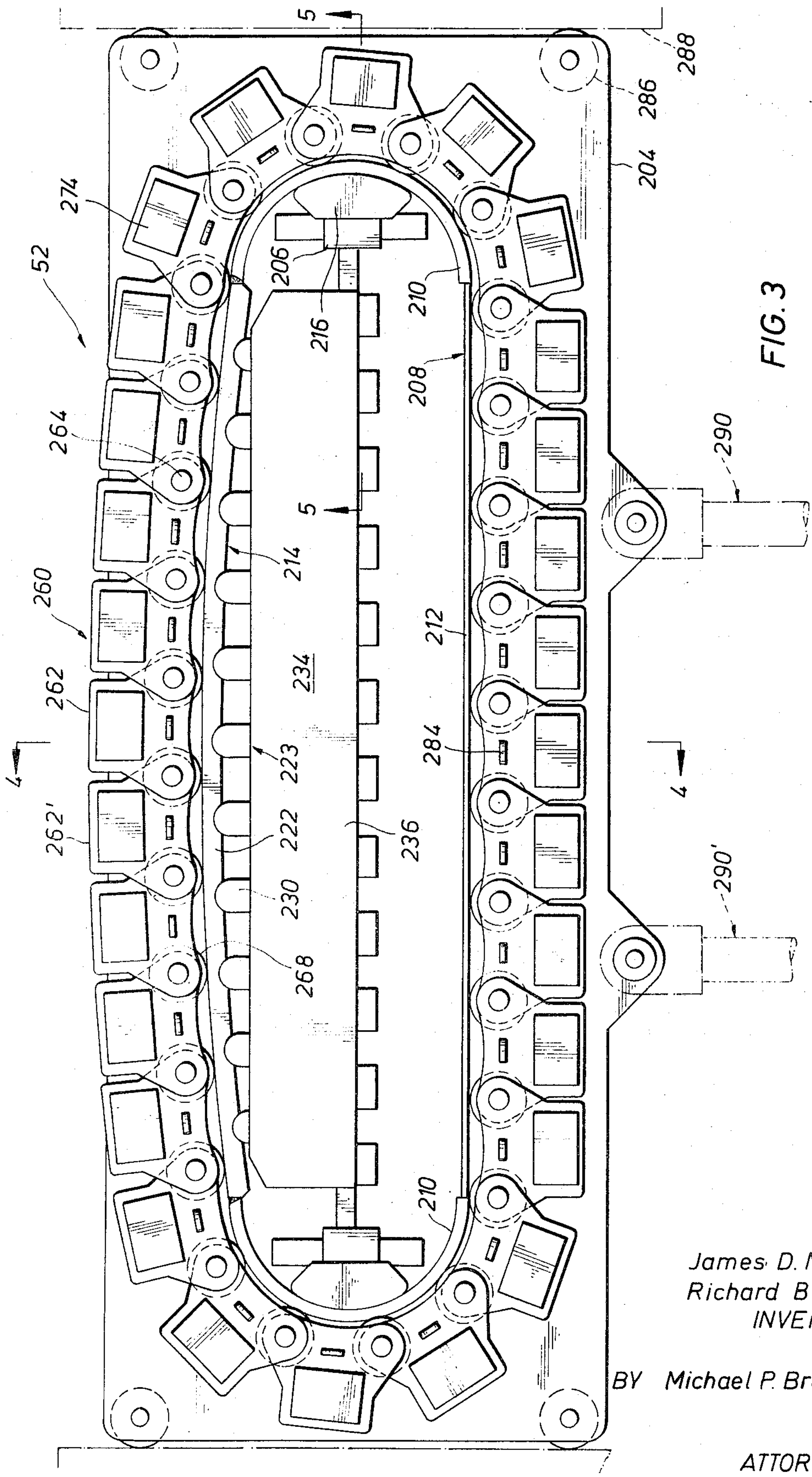

FIG. 3

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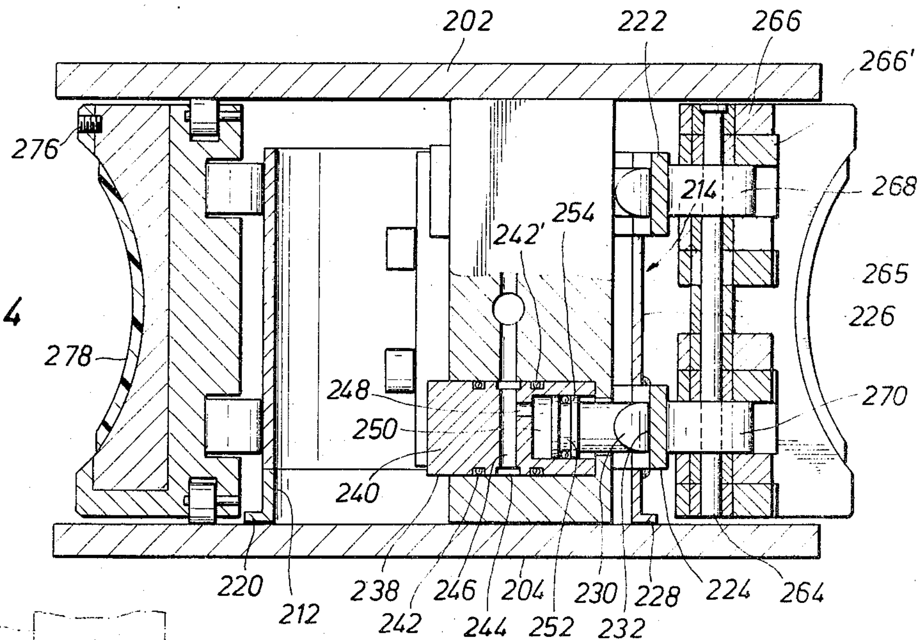
FIG. 4



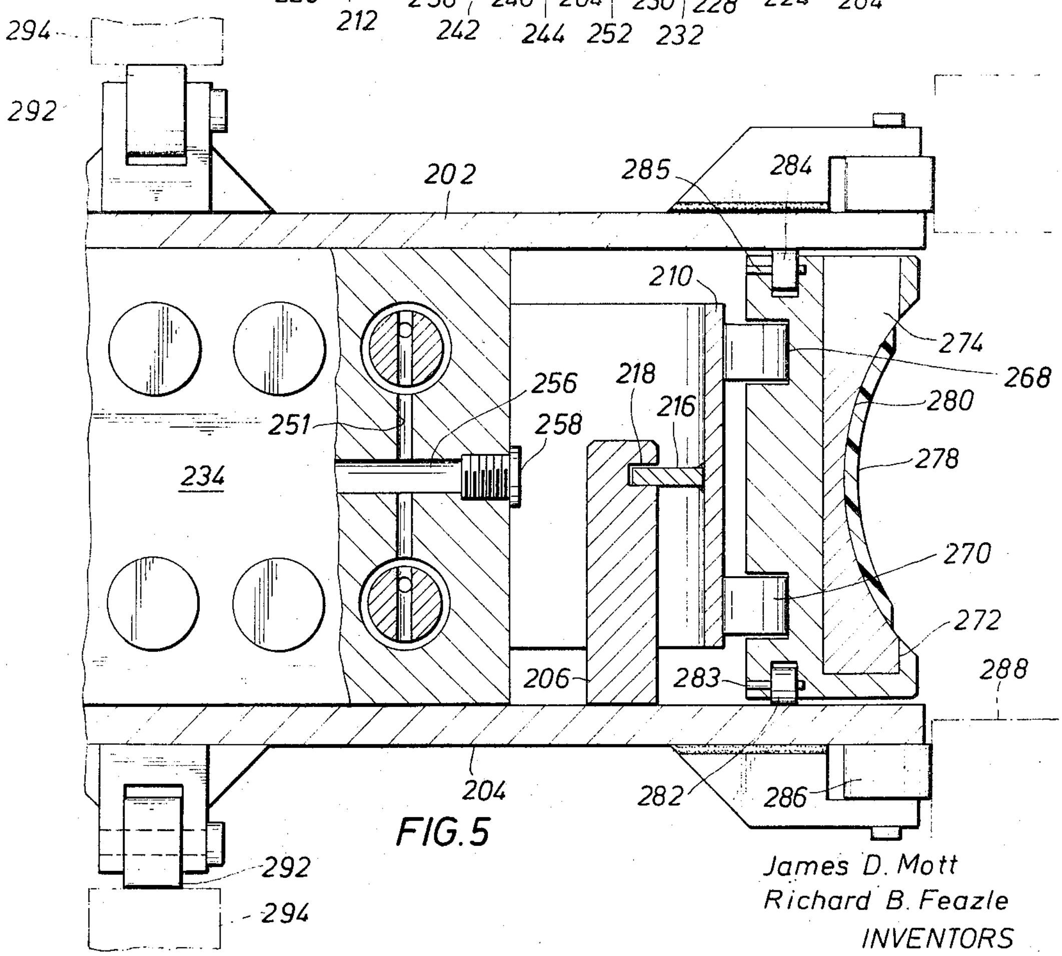


FIG. 5

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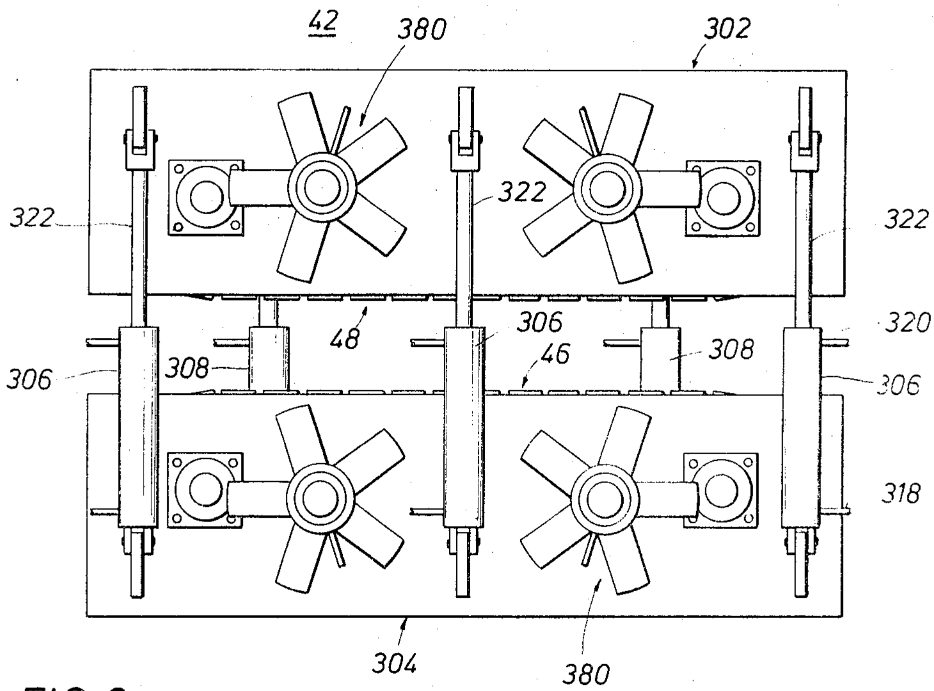

FIG. 6

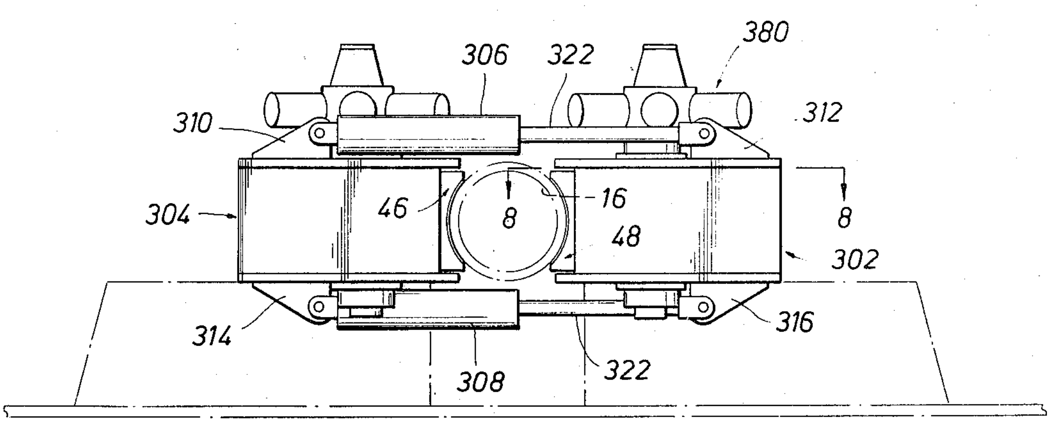

FIG. 7

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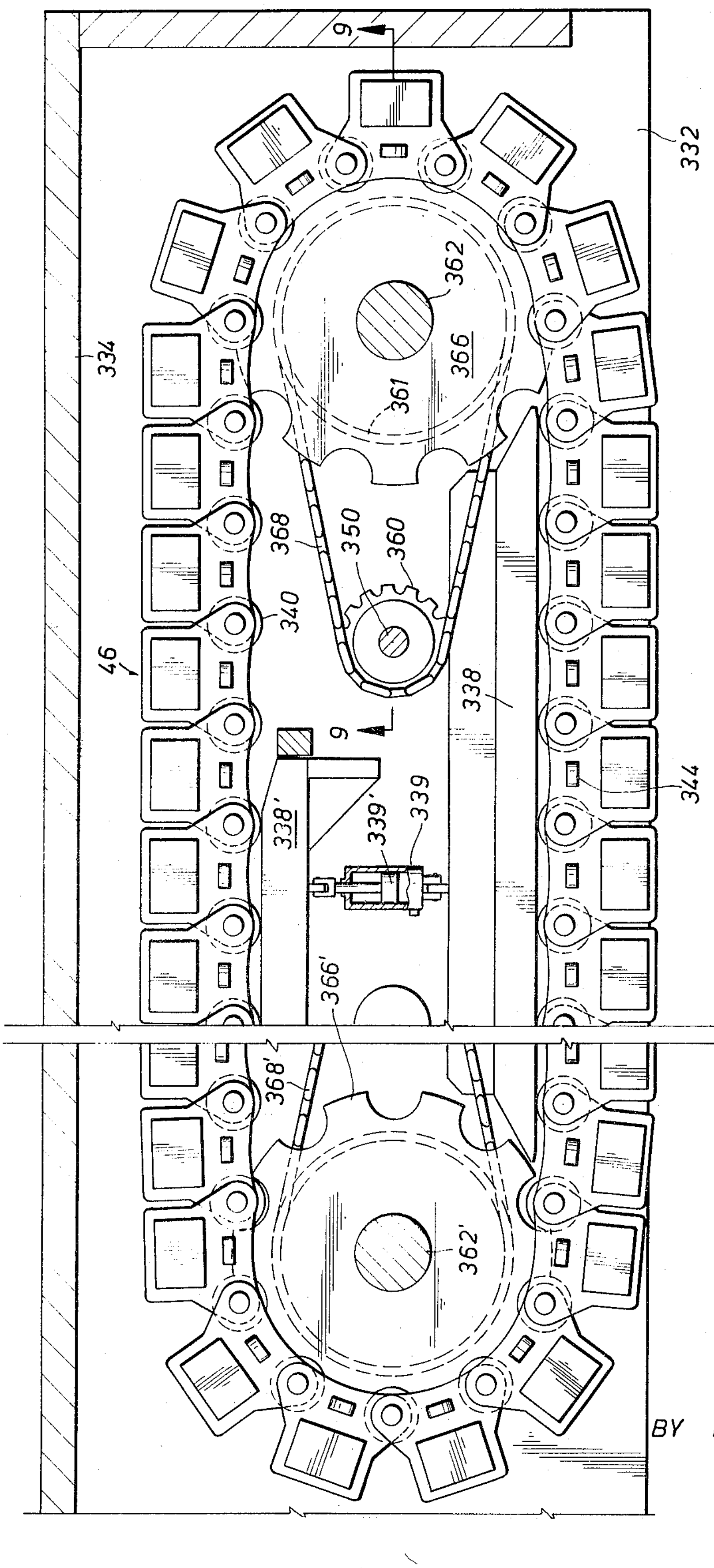

FIG. 8

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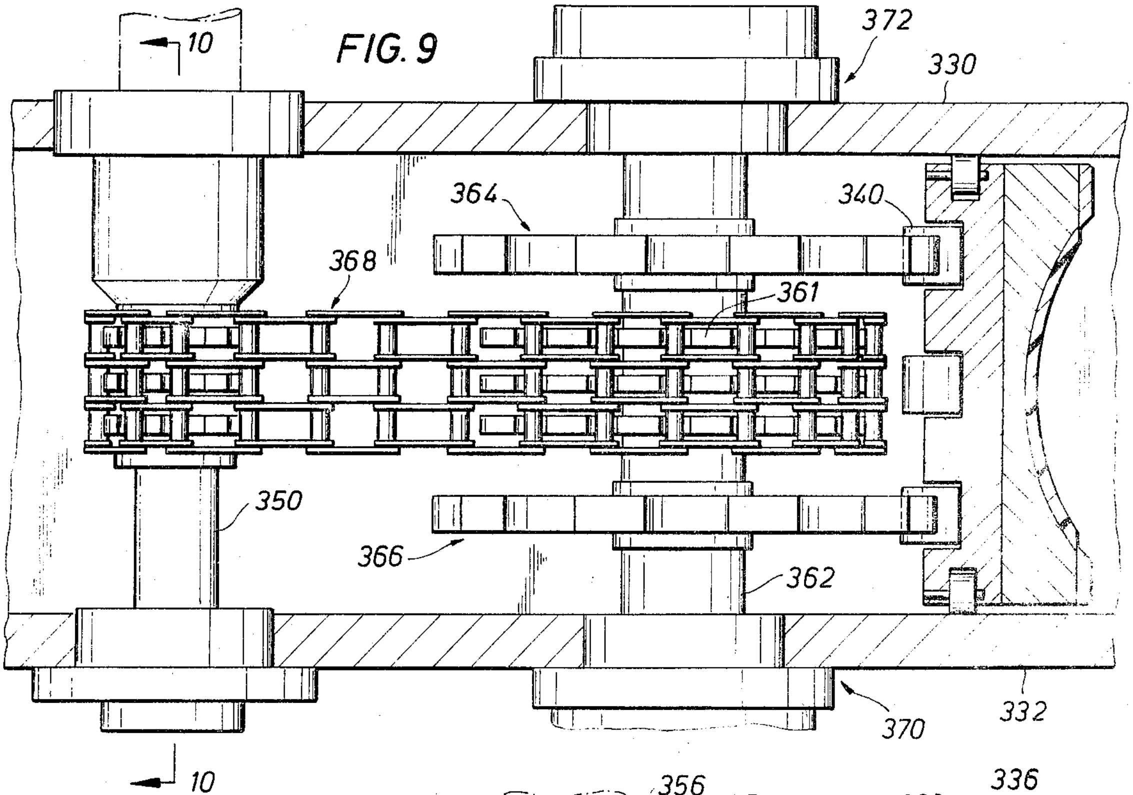
FIG. 9



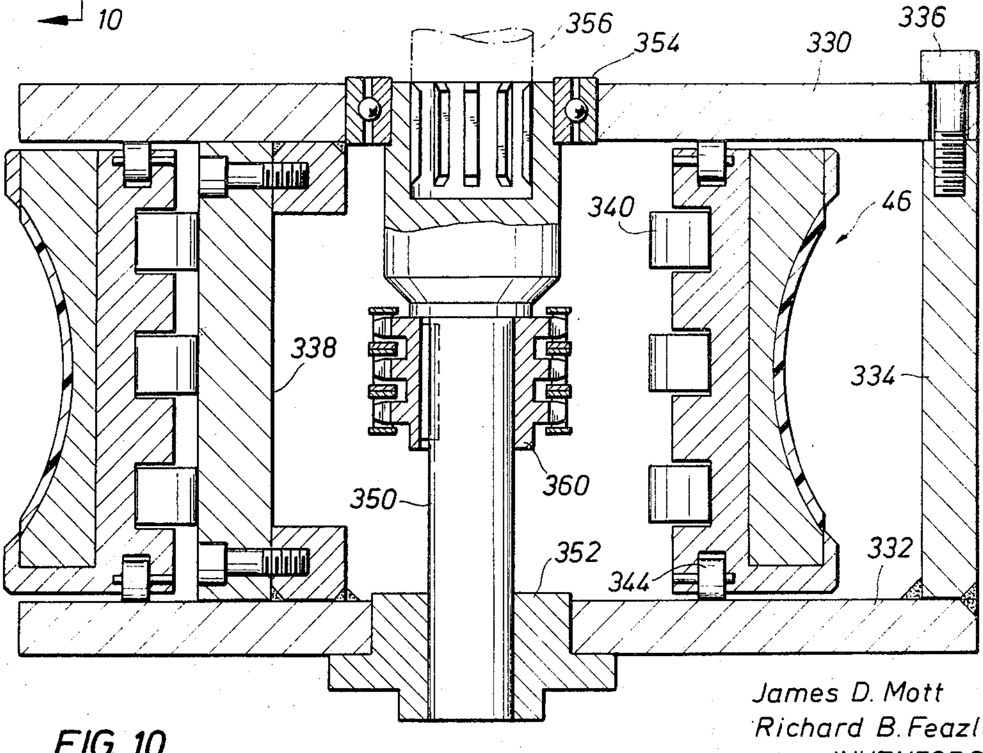


FIG. 10

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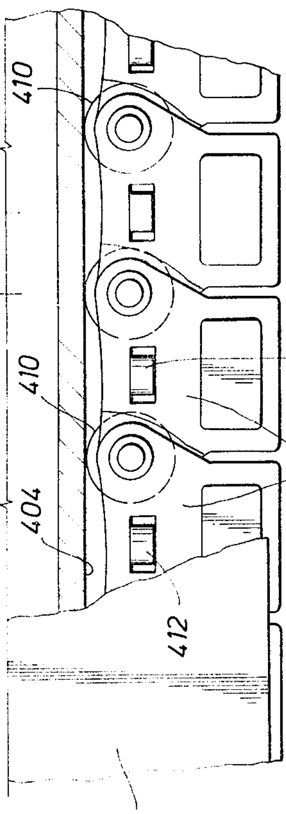

FIG. 12

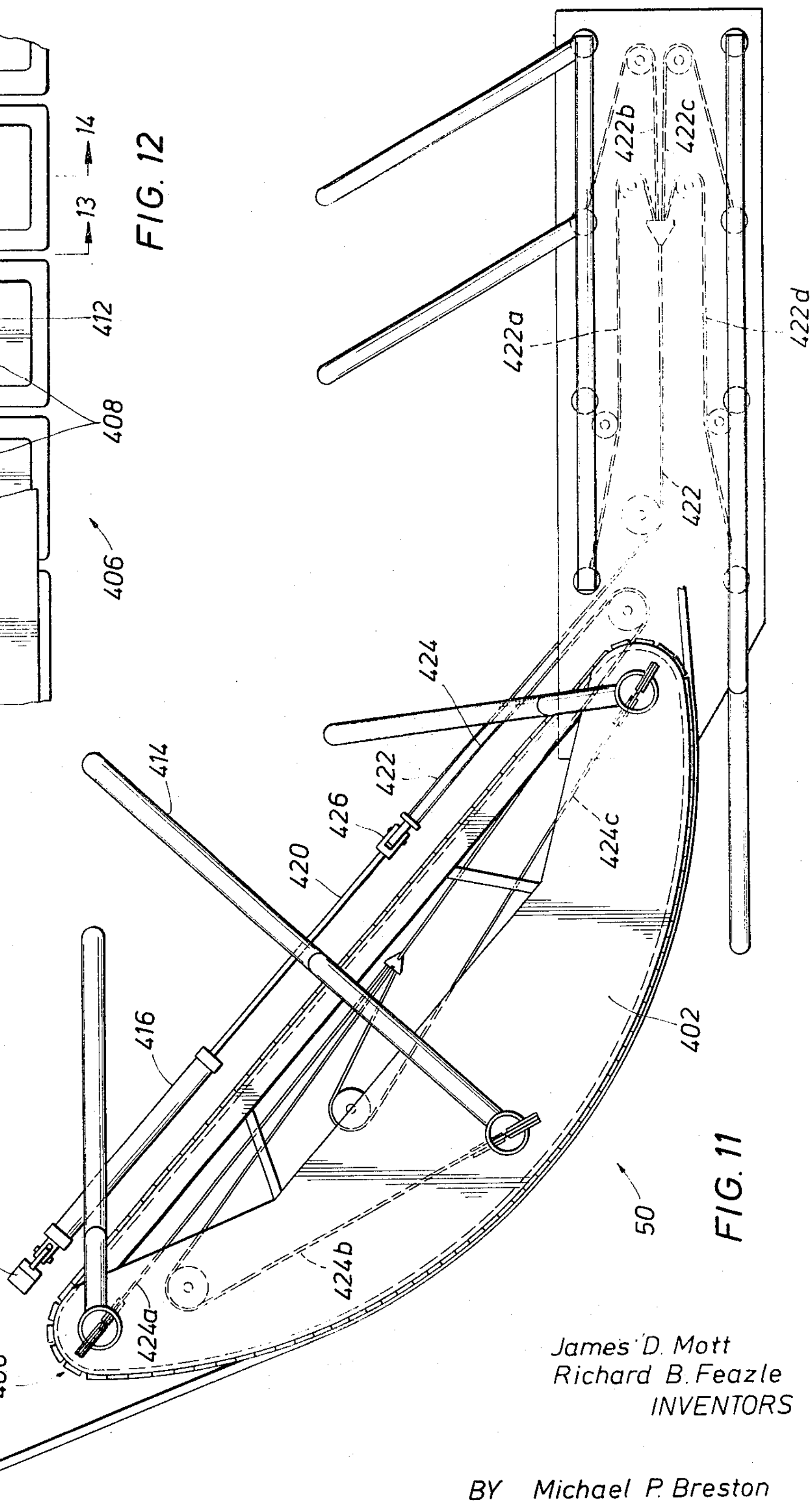

FIG. 11

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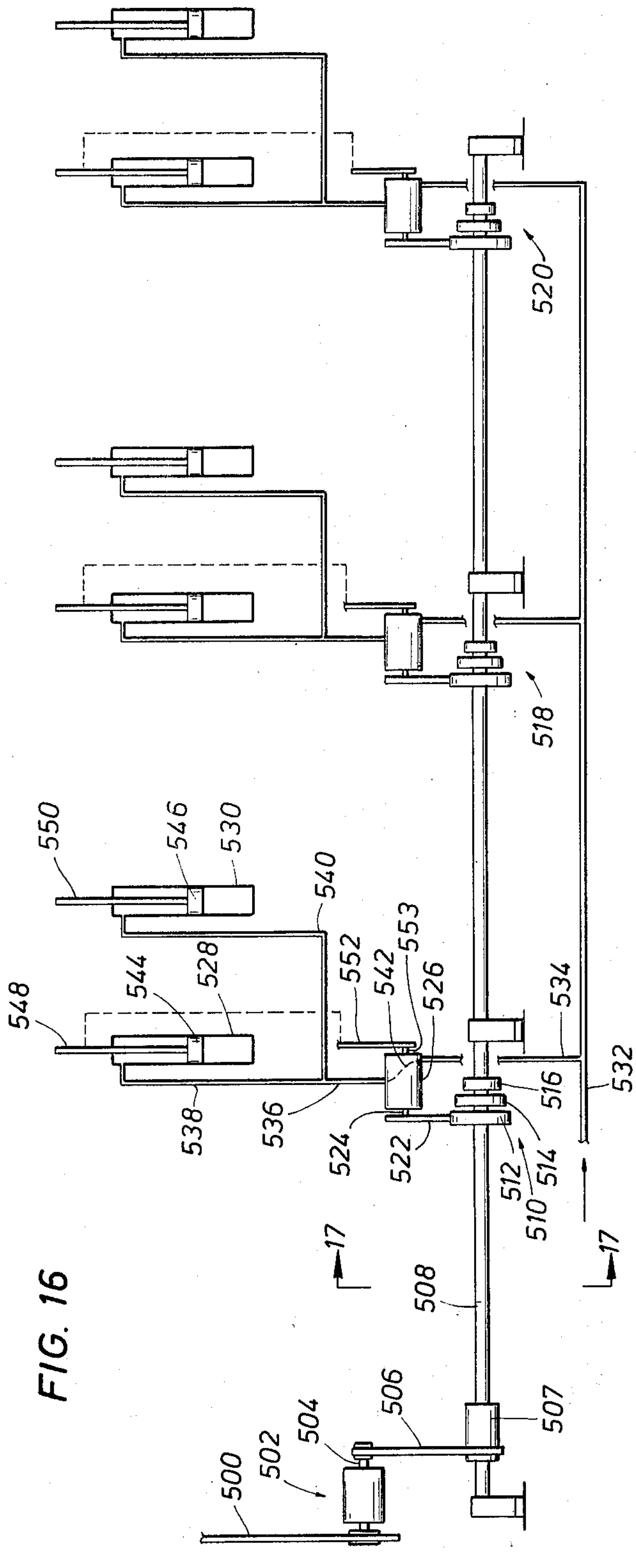

FIG. 16

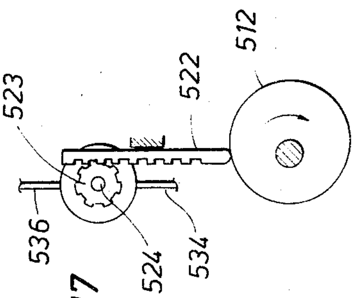

FIG. 17

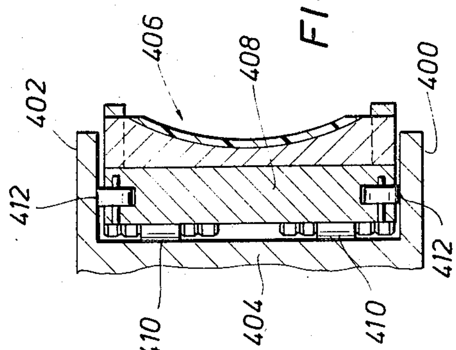

FIG. 14

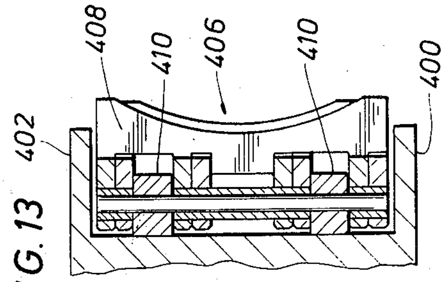

FIG. 13

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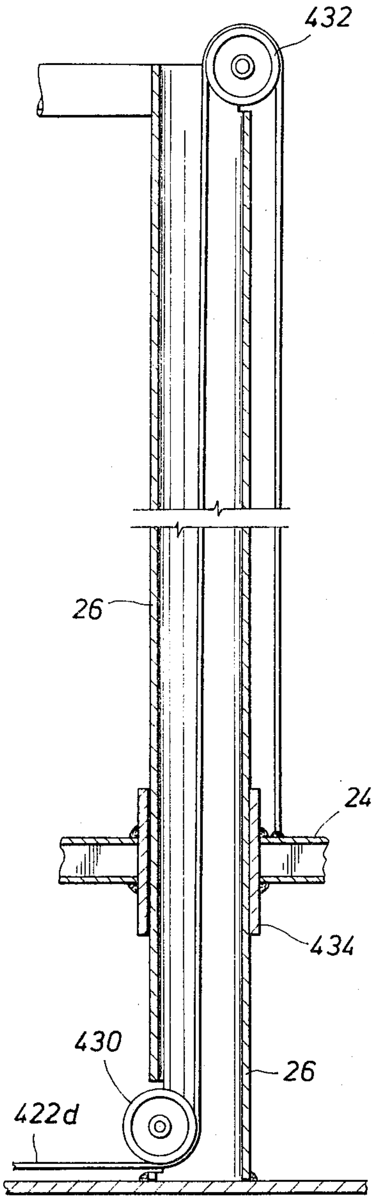

FIG. 15

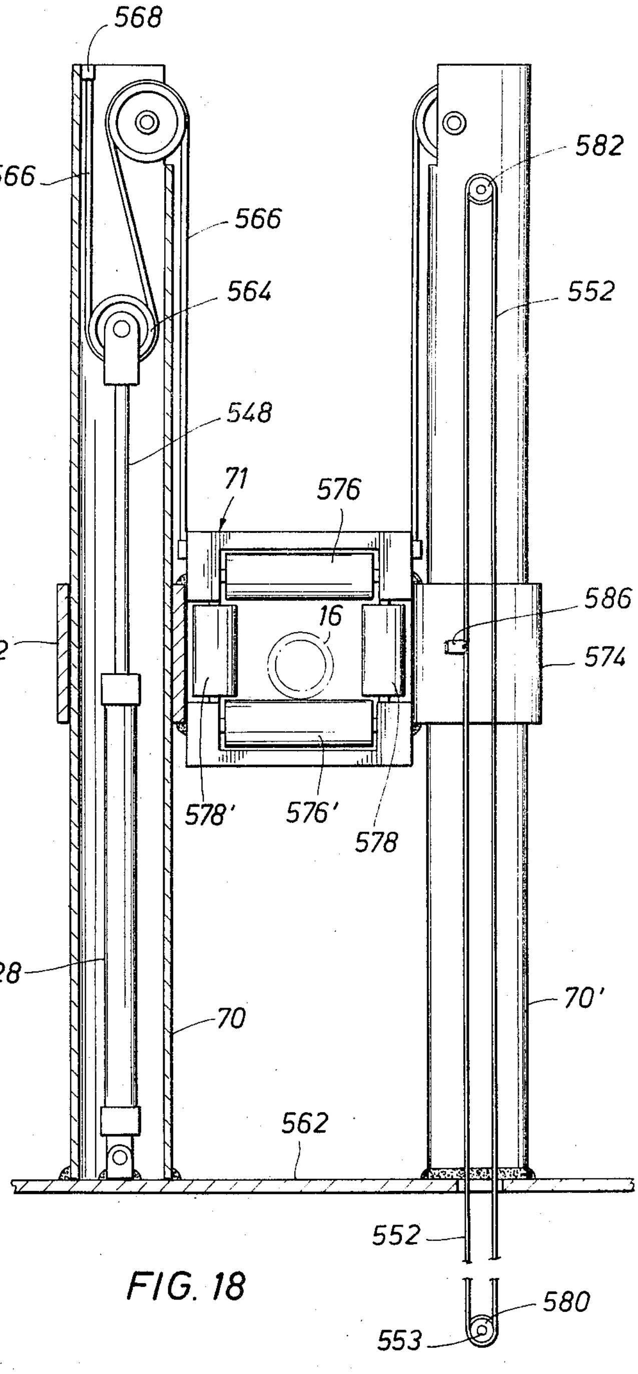

FIG. 18

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APPARATUS FOR LAYING PIPELINES

CROSS-REFERENCES TO RELATED APPLICATIONS

This invention is related to inventions disclosed and claimed in the following copending patent applications, Ser. Nos: 5,840, now U.S. Pat. No. 3,630,461 and 5,862.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to the field of processing relatively rigid members and is especially adapted for laying underwater pipelines from a reel which supports a coil of an elasto-plastic metal pipe and, more particularly, to apparatus for unwinding, straightening and processing such pipelines from a floating platform into a body of water.

2. Description of the Prior Art

A known and presently used apparatus for unwinding, straightening and processing small-to-medium diameter pipelines from a barge-mounted reel is described in U.S. Pat. No. 3,237,438. In general, the known apparatus involves, on one hand, pre-bending and winding the pipe, and on the other hand, unwinding and reverse-bending the pipe. The pre-bending and winding phase is accomplished by advancing straight sections of pipe toward a work station, joining the sections together as they progress through the work station to form a continuous pipeline, plastically prebending a span of the pipeline leading to the reel, rotating the reel preferably about a vertical axis, and winding the pipeline on the reel into a multi-layer coil. The unwinding and processing phase involves reverse-bending the span of pipe emerging from the reel and guiding under tension the straightened pipe from the barge to the floor of the body of water.

In particular, for a better understanding of the known apparatus, a detailed description will now be given, using the reference characters of the drawings in said patent. The emerging span of pipe **13** from reel **11** has its curvature removed by reverse-bending in a straightener **17** which is provided with two pairs of end rolls **41**, **43** and a center pair of working rolls **42**. Between the centers of the rolls **41** and **43** is defined a horizontal path line. The amount of straightening or reverse-bending of the emerging pipe span is determined by the horizontal distance from the center of working rolls **42** transverse to the horizontal path line. Straightener **17** is mounted on a platform **18** and is supported for reciprocal vertical movement on vertical posts to allow the horizontal path line to become in vertical alignment with each pipe convolution as it unwinds from reel **11**.

In the operation of the above apparatus one finds that the radius of curvature of the emerging pipe span from reel **11** varies from a minimum radius corresponding to the innermost pipe layer to a maximum radius corresponding to the outermost pipe layer. Since the transverse horizontal distance from the working rolls **42** to the horizontal path line is generally maintained constant, the amount of reverse-bending is also constant, irrespective of the reduction in the diameter of the unwinding coil and, hence, irrespective of the curvature in the curvilinear pipe span emerging from reel **11**. Since the transverse horizontal distance is selected

on the basis of the average curvature of the emerging pipe span, it is appreciated that the spans of pipe emerging from the outermost convolutions of reel **11** and from the innermost convolutions may not be completely straightened by straightener **17**. Incomplete straightening may leave residual bending stresses and strains within the pipeline as it emerges from straightener **17**. While the residual curvatures can be reduced in magnitude by the proper application of axial or longitudinal tension in the pipeline, they cannot be completely removed by such applied tension.

To alleviate the residual stress problem, an operator could continuously manually adjust the transverse horizontal distance between the working rolls **42** and the horizontal path line by an amount which is correlated with the instantaneous diameter of the coil as it unwinds. But, at the rate it is desired to lay the pipe, such a continuous manual adjustment would be a most difficult job, even if a skilled operator could determine by observation or from instrumentation the amount of required adjustment. It may be also contemplated to provide for the working rolls **42** automatic adjusting and positioning means, but the cost, complexity and lack of reliability for continuous use of such automatic adjusting means make such a solution rather unattractive.

Another consideration in the practice of the above apparatus stems from a variable angle of entry into the pipe straightener **17**. The above-mentioned horizontal path line is selected so as to be tangent to a middle layer in the coil, that is, to approximately bisect the angle sustained by the diameter of the full coil from the entry point to the straightener. Hence, the curved pipe span emerging from the outermost pipe layer on the coil will be at a maximum working angle of one polarity relative to this tangent in a horizontal plane, and when emerging from the innermost layer it will be at a maximum working angle of the opposite polarity. Consequently, if the pipe's path line remains stationary in a horizontal plane, this working angle will decrease as the diameter of the unwinding coil becomes reduced. If the horizontal path line were made movable transversely to follow the reduction in the coil's diameter, it would be necessary to mount the straightener both for reciprocal horizontal movement as well as for reciprocal vertical movement. A straightener so mounted would require a wide span in a horizontal plane on the deck of the barge as well as cumbersome support structures which are normally coupled to the barge for guiding the pipe onto the floor of the body of water.

Yet another consideration in the practice of prior art straighteners is the fact that in order to assure a relatively long line of contact between the rolls and the pipe, relatively large wheels or rolls are required. Since the deck space on a lay barge is limited, the requirement for large wheels cannot always be met. Another problem, associated with roll-straighteners when used to bend coated pipe, is the scraping off of coatings, welding sleeves, tape, etc. from the pipe's surface, thereby necessitating extensive repairs.

For a better understanding of the shortcomings of the prior apparatus as well as of the advantages of the present invention, a simplified review will be given of the bending stress-strain relationship within a ductile, elasto-plastic member such as a metal pipe.

In the elastic or "straight-line" range the stress is proportional to the resulting strain. When the stress is released the strain returns to its original balanced value or zero curvature. The limit of the elastic range is reached when the strain no longer returns to zero curvature. This limit corresponds to the greatest stress the pipe's material can withstand without producing a residual deflection or curvature.

In the plastic or "flat-line" range, the applied bending stress exceeds the pipe's elastic limit, and the proportional stress-strain relationship no longer holds. For a small increase in applied bending stress, there now is obtained a substantially greater increase in resulting curvature. The boundary between the elastic range and the plastic range is commonly referred to as the yield point.

As one continues to bend the pipe past its yield point, the bending stress or moment increases relatively slowly toward an ultimate value. The pipe's curvature on the other hand increases to a critical curvature at which buckling impends. After the ultimate value, the reduced resistance to bending, due to flattening, will no longer support the applied moment and the pipe will buckle. Under these conditions, the use of the pipe either as a structural member or as a conduit may be seriously affected.

Although most of the mathematical theories of plasticity deal with "ideal" plastic materials, most standard line-pipe metals deviate somewhat from the ideal. It is therefore best to experimentally establish design parameters and to measure the critical moment required to bend the particular pipe to its critical curvature. The critical moment is a function of the pipe's diameter, wall thickness and grade.

A material which is plastic becomes elastic when the applied stress is reduced in magnitude below the yield stress. Experimental curves show that upon progressively reducing the applied moment from any point on the "flat" plastic curve, there follows a descending elastic straight line substantially parallel to the original elastic line. The residual curvature is that curvature which remains after the applied moment is reduced to zero. The progressive re-application of the moment to the pipe will follow an ascending elastic straight line from the residual curvature which is substantially parallel to the original elastic line, and subsequently this ascending elastic line will join the plastic line after the yield point of the pipe's material is reached.

Since throughout this disclosure "curvature" is used extensively, a definition of the term will be given. In mathematical terms the radius of curvature of a segment of a curve is the reciprocal of the curvature K, that is 1/K, in which K is equal to the change in the direction of the curve per unit length of arc. The radius of curvature of a straight line is infinite and that of a circle is the radius used to generate the circular curve. The radius of curvature of a complex curve is a variable which depends upon the curvatures of the infinitesimally-long circular arcs located at adjacent points on the curve. An inflection point is a point where the pipe's curvature changes signs.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the above-mentioned prior art shortcomings and to provide new and improved apparatus for processing long relatively rigid members such as pipelines on and from floating platforms. The apparatus requires a minimum of adjustments, hand labor, complex instrumentation, deck space and pipe support structures.

These and other readily apparent objects are accomplished by initially bending the pipe span emerging from the reel to a desired constant radius of curvature sufficient to prevent buckling. The pipe is bent over a finite arcuate length and subsequently straightened along a selected trajectory. The straightened pipe is then diverted downwardly under suitable tension corresponding to a particular angle of inclination with respect to the water surface.

The bending, counter-bending and tensioning of the pipe is accomplished by an endless chain having blocks linked together by connecting pins. The pins also support high-load carrying rollers which ride on stiff or flexible tracks depending on the stresses desired to apply to the pipe. The flexible tracks are supported by hydraulically-operated thrust rods which cause the flexible tracks to assume a desired curvature for imparting to the pipe. When two such moving chains are oppositely positioned, the pipe is placed under tension.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top view of the overall apparatus employed in laying a pipeline;

FIG. 2 is a schematic, transverse, elevational view of the apparatus shown in FIG. 1;

FIG. 3 is a top view with upper plate removed of the bending tool used in the apparatus of FIG. 1;

FIGS. 4 and 5 are views on lines 4—4, 5—5 in FIG. 3;

FIG. 6 is a top view of the tensioner used in the apparatus of FIG. 1;

FIG. 7 is a side view in elevation of the tensioner shown in FIG. 6;

FIGS. 8 and 9 are views on lines 8—8, 9—9 in FIGS. 7 and 8, respectively.

FIG. 10 is a view on line 10—10 in FIG. 9;

FIG. 11 is a top view of the aligner in the apparatus shown in FIG. 1 together with the left mechanism for vertically reciprocating portions of the apparatus shown in FIG. 1;

FIG. 12 is an enlarged top view of a portion of the chain in the aligner of FIG. 11;

FIGS. 13 and 14 are views on lines 13—13, 14—14 in FIG. 12;

FIG. 15 is a view on line 15—15 in FIG. 1;

FIG. 16 is a schematic representation of the lifting mechanism employed in connection with the stanchions in the apparatus of FIG. 1;

FIG. 17 is a view on line 17—17 in FIG. 16; and

FIG. 18 is a view on line 18—18 in FIG. 1.

OVERALL INSTALLATION AND MODE OF OPERATION

Referring now to FIGS. 1 and 2, wherein the showings are for the purpose of illustrating the preferred apparatus of the invention only, and not for the purpose of limiting same, a suitable barge 10 supports a reel 12 for rotation about a vertical axis 11. Reel 12 winds and unwinds a continuous length of pipeline 16. While reel 12 is shown mounted for rotation about a vertical axis, it is appreciated that it could be equally mounted for rotation about a horizontal axis, but with appropriate changes in the positions of the pipe processing elements.

Pipeline **16** is preferably made of an elasto-plastic steel material of a suitable grade and may have a relatively large diameter, say between 4 to 12 inches, and even higher. For example, a standard X-Grade pipe could be a 12 inch line pipe, Schedule 20 through 80, API 5L, Grade B, seamless, or a 6 inch line pipe, Schedule 20 through 180. For underwater applications, pipeline **16** is ordinarily covered with a suitable protective coating, although such coating is not essential.

It has been found, contrary to what might be expected, that neither the coating nor the pipeline becomes damaged by the consecutive bending and reverse-bending operations contemplated by the method of this invention.

Reel **12** can be rotated by any known suitable means. During the winding and unwinding operation, a span of pipeline **16** passes through an apparatus **14** which includes a combined bending and level wind apparatus **18** and a tensioner **42**. System **14** is mounted on a frame **24** which is reciprocable vertically on a plurality of posts **26**.

To facilitate the winding of pipeline **16**, the core **28** of reel **12** is made frusto-conical. The construction of reel **12** and the manner of its operation is fully described in copending application, Ser. No. 5,840 , assigned to the same assignee. Pipeline **16** is wound into a multi-layer coil **30**. Each pipe layer includes several pipe convolutions **32**. The radius of curvature of the pipe's span **34** when emerging from the innermost layer **36** has the smallest radius of curvature and when emerging from the outermost layer **38** has the largest radius of curvature. Also, within each layer, the radius of curvature decreases as the pipe span **34** emerges from the bottom convolution to the top convolution.

As can be seen from FIG. **1**, when the pipe span **34** emerges from the outermost layer **38** it is at a relatively small angle A from a transverse horizontal line B, and when it issues from the innermost layer **36** it is at a relatively large angle C from line B. Thus, the emerging pipe span **34** has a variable angle of entry into the bending apparatus **18**. The instantaneous magnitude of the angle depends on the diameter of the particular convolution **32** from which pipe span **34** emerges.

The exact configuration of the emerging pipe span **34** between reel **12** and apparatus **18** depends on the physical characteristics of pipeline **16** and the stresses within the pipe. An inflection point **40** occurs within the emerging pipe span **34** between reel **12** and bending apparatus **18**. Before reaching point **40** from reel **12**, the span **34** has a positive curvature, and following point **40** a negative curvature. The terms positive and negative have been arbitrarily selected only for ease of description. As herein employed, a positive curvature is a curvature the radius of which has a center below the path of span **34** (as shown in FIG. **1**) and, conversely, a negative curvature has its center above the path of span **34**.

The inflection point **40** is therefore a point where the pipe's curvature changes signs. The bending apparatus **18** is adapted to receive the emerging span **34** at a variable angle of entry and at a variable curvature and to automatically bend the pipe so as to render it substantially free of residual stresses and strains for subsequent use during the pipe-laying operation.

Bender **18** is designed to compound-bend the emerging pipe span **34** and includes three tools **50, 52** and **54** positioned at spaced locations relative to each other and to reel **12**. Pipe span **34** is extended through these tools, as shown. The peripheral face of each tool has a movable chain bearing resilient blocks that are arcuately shaped to receive and closely engage against one side of the pipe span. The radius of curvature of each chain in each of tools **52** and **54** is adjustable from an infinite radius of curvature (flat) to a minimum radius sufficient to prevent pipe buckling, thereby allowing the variation of the amount of curvature imparted to or removed from the pipe span **34**. The bending tool **50**, on the other hand, applies a transverse force in a horizontal plane operable to impart to pipe span **34** a negative curvature corresponding to the radius of curvature of its peripheral face in engagement with the pipe span **34**.

During the winding operation, pipeline **16** is plastically bent by yielding the metal of the pipe to set a positive curvature in each convolution **32**. During the unwinding operation, bending tool **50** stresses the emerging span **34** as it passes through bender **18** to thereby yield the pipe's material and to plastically bend span **34** to a negative curvature having a constant radius sufficient to prevent buckling the pipeline.

Accordingly, the emerging pipe span **34** exiting from bending tool **50** at a tangent point **56** will have a constant negative plastic curvature and a uniform stress distribution, irrespective of the diameter of the unwinding coil **30**. Hence, the pipeline when entering bender apparatus **18** has both a non-uniform curvature and a non-uniform stress distribution, and when exiting from tool **50** has both a uniform curvature and a uniform stress distribution, irrespective of the diameter of the unwinding coil. Therefore, bending tool **50** may be considered as a stress uniformizer and as a curvature uniformizer.

Pipe span **34** is plastically bent on bending tool **50** over a finite selected arcuate length and exits from tool **50** tangent to point **56**. It is the function of the remaining tools to transform the curvilinear profile of span **34** into a rectilinear profile. For this purpose the center bending tool **52** applies a moment to the pipe span **34** which imparts to it a positive curvature. This is accomplished by plastically reverse-bending pipe span **34** to a particular positive curvature. Thereafter, as the pipe moves past tool **52** and toward tool **54**, the induced bending moment in span **34** is unloaded along a linearly elastic path, resulting in a pipe profile which is substantially rectilinear and which is characteristic of a state of substantially zero net moment in the pipe span **34**. The rectilinear pipe span **34** will discharge on and be colinear with the desired trajectory which has a selected angle with respect to the surface of the body of water.

The tension-control mechanism **42** maintains the emerging pipe span **34** under tension while it is being compound-bent by bender apparatus **18**. The tensioner **42** in the preferred embodiment includes two opposed track chains **46,48**, at least one of which is powered for rotation. Each chain also bears resilient blocks having a groove therein so shaped as to receive and snugly engage one side portion of the pipe. The chains move in the directions indicated by the arrows 49 during the unwinding operation and they also assist in pulling the pipe off reel 12.

Tool 54 defines with the center line of the tensioner 42 a horizontal path line 60, and the amount of working or bending by tool 52 is determined by the adjustable, transverse, horizontal distance from the periphery of tool 52 to this horizontal path line, as will be appreciated by those skilled in the art. It will be apparent that the pipe span 34 between tools 50 and 52 sustains a sign reversal in its curvature and has a second inflection point 62 near bending tool 52. The curvature of the peripheral face of the center or working tool 52 is adjustable to accommodate pipes of varying diameters through the bender 18.

One or more guide structures or stanchions, generally designed as 70, carry supports 71 for guiding the rectilinear pipeline 16 exiting from the tensioner 42 along a vertically inclined pipe processing path 72 to facilitate the pipe's entry into the body of water.

Suitable means 72 are employed to reciprocate vertically the supports 71 and the platform 24, on which are mounted tools 50, 52, and 54, as well as tensioner 42. The reciprocation is synchronized with the rotation of reel 12.

The apparatus 14 of the present invention allows the unwinding of a pipeline from a reel at a relatively high rate of speed without the need to continuously manually or otherwise adjust the bending tools of conventional benders. The apparatus accepts pipe of varying diameters and is especially beneficially employed with relatively-large diameter pipes, up to 12 inches and higher. The emerging curvilinear pipe from the reel is rendered substantially rectilinear without unbalanced residual moments remaining therein. Also, the system is substantially independent of the prior loading history of pipeline 16.

STRAIGHTENER APPARATUS AND MODE OF OPERATION

Referring to FIGS. 1 and 3–5, there is shown the structure of bending tool 52 which is identical to bending tool 54. Bending tool 52 has a top plate 202 and a bottom plate 204, each preferably made of steel. Welded to the bottom plate 204 are two upright supports 206 for supporting a track assembly, generally designated as 208. Assembly 208 is oval shaped and includes two curved side tracks 210, a long rear track 212 and a long front track assembly 214. Each side track 210 is supported by a shoulder 216 slidably positioned in a recess 218 near the top of support 206. The rear track 212 is stiff and has a leg 220 resting on the bottom plate 204. The front track assembly 214 includes two relatively flexible chain tracks 222 and 224 separated from each other by a flexible plate 226 which also rests on a leg 228 supported by plate 204.

Each of flexible tracks 222 and 224 is supported by an array 223 of support rods 230. Each rod 230 engages its flexible track in a slightly recessed area 232. To move rods 230 there is provided a hydraulic system generally designated as 234 having a main body 236 extending entirely between plates 202 and 204. Body 236 defines a plurality of cylinders 238. Fitted inside each cylinder 238 is a cylindrical insert 240. Two O-rings 242 and 242′ seal off a circumferential groove 244 which is in fluid communication with a transverse bore 246. Bore 246 communicates through an axial bore 248 with a cylinder chamber 250. The fluid pressure in cylinder 250 actuates a piston 252 which is fixedly secured to and slidably mounted with a bottom piston 254 of rod 230. Consequently, rod 230 reciprocates together with piston 252 in cylinder 250. Each cylinder 250 is in fluid communication through a branch line 251 with a main fluid reservoir 256 having a threaded cap 258.

The chain assembly is generally designated as 260 and is composed of a plurality of pairs of blocks 262 and 262′, each pair is interconnected by linking pin 264 in a bushing 265. Each block 262 has four ears 266 overlapping four ears 266′ of an adjacent block 262′. Also rotatably supported and suitably separated on pin 264 are two main rollers 268 and 270. Roller 268 rolls on flexible track 222 and roller 270 rolls on flexible track 224. Each chain block 262 or 262′ is provided with an insert space 272 for removably accepting an insert 274 which is secured to block 262 by a set screw 276. The insert can be easily changed when the top plate 202 is removed. Insert 272 has a rubber-bonded liner 278 on its external cylindrical surface 280. Liner 278 is preferably made of polyurethane to better protect the pipe's coating. Liner 278 is in engagement with the pipe 16 being straightened. Each block 262 is also provided with two small vertical-positioning rollers 282, 284. Roller 282 is mounted on shaft 283 and rides on the bottom plate 204 and roller 284 is mounted on shaft 285 and rides on the upper plate 202.

Plates 202 and 204 are provided with four horizontal end rollers 286 which ride on vertical rails 288 to allow the entire assembly 52 to move in a generally transverse horizontal direction perpendicular to path 60 in FIG. 1. This is accomplished by two hydraulic cylinders 290, 290′ actuated from a hydraulic source (not shown). Plates 202 and 204 are also provided with one or more pairs of vertical rollers 292 which ride on horizontal rails 294. In this fashion the assembly 52 can be freely moved by the forces produced by the cylinders 290 and 290′.

The fundamental objects of the bending tools 52 and 54 are (1) to apply the required high transverse forces to the emerging pipe span 34 in order to straighten it, (2) to position and maintain the pipe in a proper deflected configuration required for straightening, and (3) to protect both the pipe and its coating from damage due to excessive concentrated pressures and/or from differential tangential velocities between the pipe and the chain blocks 262. These objects are achieved primarily by (1) providing for each block 262 the flexible liner pad 278 which contacts the pipe over a relatively long span and by (2) supporting the flexible tracks 222 and 224 on an array of movable rods 230 connected for operation to the common fluid reservoir 256. In this fashion, each rod 230 transmits substantially the same pressure to each contact face 278 and hence to the engaged portion of the pipe. The relatively long roller tracks 222 and 224 assume substantially the same curvature as the pipe being engaged by the chain 260. Since the curvature of the flexible tracks 222 and 224 is relatively small, it will be appreciated that there may only be an infinitesimal variation in the tangential velocities of the moving pipe and the moving blocks 262 of chain 260 which contact the pipe.

This is in contra-distinction to the prior art straighteners employing wheels where the concave face on the periphery of the wheel provides portions with siginificantly different radii from the center of the wheel. Since all portions of the wheel have to rotate at the same angular velocity at any one instant, the tangential velocity of any point on the periphery of the wheel depends on its distance to the center of the wheel. Accordingly, since the pipe moves in essentially a linear-type motion, there exists in known straighteners relative tangential velocities between those portions of the wheel which contact the pipe and which are at different radii from the center of the wheel. As a consequence, there occurs scrubbing of the pipe as well as of the wheel surface in contact with the pipe.

In the apparatus of this invention, any scrubbing action between the chain block faces and the pipe is substantially eliminated. The bender 52 can be considered as a portion of a relatively large radius wheel, i.e., the benefits of a large radius wheel are obtained without having to occupy very valuable deck space. The portion of the wheel provides a long line of contact with the pipe which could only be obtained with a very large radius wheel.

Scrubbing between the chain blocks and the pipe is further reduced due to the configuration of the curved side tracks 210. The radius of the side track 210 is relatively short compared to the radius of the main track 214. Accordingly, when the support blocks 262 move from the region of contact with the pipe 16 to the transition region between the main track 214 and the side tracks 210, they accelerate much more rapidly away from the pipe in a direction perpendicular to the longitudinal axis of the pipe, and therefore they rapidly disengage from the pipe. Inversely, when the blocks 262 move toward the main track they rapidly engage the pipe. Another manner of explaining this phenomenon is to measure the acceleration of a front roller (in the direction of motion) and that of a rear roller of a particular chain block 262 moving toward a side track 210. Since the distance between their pivot pins 264 is relatively larger than the contact surface 278, this contact surface 278 will "fall" in line and "-fall-out" of line very rapidly, thereby reducing any tendency of scrubbing the pipe's surface.

All the pistons 252 have the same area and, consequently, since they are connected to a constant volume hydraulic fluid reservoir 256 they will be loaded uniformly and transfer this uniform load to the pipe's surface in engagement with chain 260. Any displacement by any one of the rods 230 in the array 223 must be compensated by an equal displacement of the other pistons in the array to ensure that a constant fluid volume is maintained. This uniform pipe loading provided by each array of rods 230 is highly desirable in order to prevent large local load concentrations especially at the leading and trailing edges of the bending tool 52.

It will also be appreciated that the curvature of the flexible track 214 may be positive or negative (concave or convex) depending on the curvature desired to impart to the emerging pipe span 34. Thus while tool 52 presents a convex curvature, tool 54 presents a concave curvature in the arrangement shown in FIG. 1.

TENSIONING MECHANISM AND MODE OF OPERATION

Referring to FIGS. 1 and 6–10, the tensioning mechanism 42 includes two identical sub-assemblies 302 and 304, the separation between which is controlled by three top cylinders 306 and three bottom cylinders 308, cylinders 306 are mounted between ears 310 and 312 and cylinders 308 between ears 314 and 316. Each cylinder 306 is provided with two hydraulic lines 318, 320 for extending or retracting its rod 322, in a conventional manner. Each cylinder 308 is equally driven by hydraulic lines. Since the two sub-assemblies 302 and 304 are in all respects identical, only sub-assembly 302 will be described in detail.

Sub-assembly 302 includes a top plate 330 and a bottom plate 332. A semi-cylindrical side wall 334 has one end welded to the bottom plate 332 and the other end is secured to the upper plate 330 by a bolt 336. A roller-track 338 between plates 330 and 332 serves both to provide a riding track for the main rollers 340 of a chain assembly 46 and to provide another side wall between plates 302 and 304. The chain 46 also has small vertical-positioning rollers 344 and is similar in construction to the chain assembly 260 previously described in connection with FIG. 3, except that three main rollers 340 are now mounted on each interconnecting linking pin instead of the two main rollers 268 and 270 previously described.

To drive chain 46 there is provided a drive shaft 350 which is supported for rotation by end bearings 352 and 354. A motor shaft 356 meshes with and drives the drive shaft 350. Mounted on shaft 350 is a three-strand drive sprocket 360. A driven sprocket 361 is mounted on a driven shaft 362 which also provides support for and rotates two large sprockets 364 and 366. Driven shaft 362 is suitably mounted in end bearings 370 and 372. A three-strand roller chain 368 provides power transmission between shafts 350 and 362. The top row of rollers 340 bears on the sprocket teeth of sprocket 364 and the bottom row of rollers 340 bears on the teeth of sprocket 366. In this fashion, the rotation of shaft 362 is transmitted by sprockets 364 and 366 to the chain assembly 46.

Since large torques are involved, it is desired to provide another drive shaft assembly, identical to the drive shaft assembly of shaft 362, for driving a shaft 362′ supporting sprockets 366′, etc., which also drives the chain assembly 46. Each motor shaft 356 is driven by a motor 380 preferably of the hydraulic type. Four such hydraulic motors 380 are provided, one for each motor shaft 356. Two such motors are positioned above plate 330.

In operation, shafts 362 and 362′ are driven in the same direction, either clockwise or counterclockwise, by their respective drive shafts and sprockets. For example, the rotation of the motor shaft 356 causes the rotation of the drive shaft 350, sprockets 360 and 361, chain 368, shaft 362, sprockets 364 and 366, and hence chain assembly 46. Chain assembly 46 will rotate in the direction 49 (FIG. 1) or in an opposite direction.

Rollers 340 bear on the sprocket teeth and also ride on the solid stiff track 338. To avoid slack in the chain assembly 46, a shorter opposite roller track 338′ is also provided which is separated from track **338** by a movable transverse support, generally designated as **339**. Support **339** includes hydraulically operated pistons **339'** for maintaining a predetermined separation between tracks **338** and **338'**.

The simultaneous actuation of the top and bottom cylinders **306** and **308** will cause their rods **322** to extend or retract thereby reducing or increasing the applied pressure on pipe **16** passing between the chains **46** and **48** of the assemblies **302** and **304**, as shown in FIGS. **1** and **7**.

THE ALIGNER MECHANISM AND MODE OF OPERATION

Referring now to FIGS. **1** and **11–15**, the bending tool **50**, since it aligns the pipe for straightening by tool **52**, will hereinafter be called the "aligner." Aligner **50** includes a bottom plate **400**, a top plate **402** and an arcuate roller track **404**. A roller chain assembly **406** carries a plurality of blocks **408**, each block having two main rollers **410** and two vertical positioning rollers **412**. The construction of chain **406** is in all respects similar to the construction of chain **260** previously described, as is evident from FIGS. **13** and **14**. Rollers **410** ride on the rigid track **404** when the chain **406** is caused to move by the friction created by the movement of the emerging pipe span **34**.

In FIG. **11** is shown the manner for supporting aligner **50** as well as platform **24**. Posts **26** are provided with suitable braces **414** for adding the required structural rigidity. A main hydraulic cylinder **416** is fixedly secured at one end to a support **418**. The operating rod **420** of cylinder **416** is connected to two parallel cables **422** and **424** through a joint coupling **426**. Line **422** branches out into lines **422*a***, **422*b***, **422*c*** and **422*d***. Similarly, line **424** is divided into lines **424*a***, **424*b***, and **424*c***. Cylinder **416** and hence rod **420** is actuated by a hydraulic system (not shown).

The manner of attaching a cable such as **422*d*** to the platform **24** is shown in FIG. **15**. For example, the cable passes over a direction-change pulley **430** into post **26**, over another direction changing pulley **432**, and its end is attached to platform **24** which is secured to a sleeve **434** slidably mounted on post **26**. Consequently, a displacement of rod **420** is translated into a corresponding proportional displacement of platform **24** and of aligner **50**.

STANCHION MECHANISM AND OPERATION

Referring now to FIGS. **1**, **16–18**, connected to platform **24**, in any suitable manner, is a positioning rod **500** which moves linearly in a vertical plane in correspondence with the displacement of platform **24**. A suitable transmission **502** translates the linear displacement of rod **500** into an angular displacement of a shaft **504**. Shaft **504** drives a belt **506** which in turn drives a pulley **507** on a main shaft **508**. Mounted on shaft **508** are three sets of cams **510**, **518** and **520**, one set for each pair of stanchions **70**. Set **510** includes cams **512**, **514** and **516**. Since the operation of the three cam sets is identical, only the operation of cam set **510** is described.

Cam **512** (see FIG. **17**) has its shape predetermined in accordance with the diameter of pipe **16** to be processed, the same holds for cams **514** and **516**. Shaft **508** can be shifted to the right or to the left depending on the size of pipe being processed, thereby engaging a corresponding cam from each set. Rotation of cam **512** is transmitted via a cam follower **522** and a sprocket **523** to the input shaft **524** of a conventional hydraulic feedback valve **526** which drives two cylinders **528** and **530**. The fluid for valve **526** and cylinders **528** and **530** is supplied from a main fluid line **532**. A branch line **534** is connected to the inlet of valve **526**. The output line **536** from valve **526** provides two branch lines **538** and **540**, respectively coupled to cylinders **528** and **530**.

Rotation of shaft **524** corresponding to a displacement of platform **24** causes fluid flow as shown by the dotted line **542** between branches **536** and **534**, thereby moving pistons **544** and **546** in cylinders **528** and **530**, respectively. Pistons **544** and **546** are provided with rods **548** and **550**, respectively.

A feedback chain **552** (FIG. **18**) causes a feedback shaft **553** of valve **526** to rotate in a manner as to discontinue the fluid flow between branches **536** and **534**. Rods **548** and **550** will now remain in this new position until another input is supplied by rod **500**.

In FIG. **18** is shown a pair of stanchions **70**, **70'**. Stanchion **70** is shown in cross-section and stanchion **70'** in elevation. The stanchions are fixedly mounted on the deck or ramp **562** (FIG. **1**) Cylinder **528** is mounted in stanchion **70** and cylinder **530** is mounted in stanchion **70'**, as shown. Secured to the end of rod **548** is a sheave **564**. A cable **566** has one of its ends fixedly attached to a support **568** and its other end to the pipe support or carriage **71**. Carriage **71** is mounted on tubular sleeves **572** and **574**, slidably mounted on stanchions **70** and **70'**, respectively. It will be appreciated that the extension of rods **548** and **550** will cause carriage **71** to move downwardly, and, inversely, the retraction of rods **548** and **550** will cause carriage **71** to move upwardly. Carriage **71** is provided with two rollers **576** and **576'** each mounted for rotation about a horizontal axis and with two rollers **578** and **578'** each mounted for rotation about a vertical axis. The straightened pipe **16** passes between the rollers as shown. Mounted on the feedback shaft **553** is a sprocket **580** and mounted near the top of stanchion **70'** is another sprocket **582**. The endless roller chain **552** rides on sprockets **580** and **582**. A clamp **586** fixedly secured to sleeve **574** and to chain **552** causes the chain to move clockwise or counter-clockwise depending on the direction of linear movement of sleeve **574**. Motion of chain **552** is transmitted to the feedback shaft **553** thereby reducing the fluid flow as previously explained.

While this invention has been described with reference to specific embodiments it will be apparent that many modifications may be made in the apparatus particularly disclosed herein. The invention therefore is not to be limited to the preferred embodiments shown in the drawings but rather only by the scope of the appended claims.

What is claimed is:

1. An apparatus for operating on a relatively-inflexible movable pipeline, said apparatus including:

a first pipe-engaging tool, said tool comprising:

a first continuous chain;

a first series of spaced blocks supported by said chain, said blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other;

a series of rollers on said pins;

first roller-support track means, said rollers being adapted to roll on said track means;

means operatively coupled with said first tool for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses;

said first track means including relatively-flexible track portions for supporting the rollers which are associated with said pipe-engaging blocks;

hydraulically-operated means comprising longitudinally-displaced support rods for supporting said flexible track portions,

said support rods providing substantially-uniform support to said portion of said pipeline engaged by said first tool, and said support rods being automatically and reciprocatingly movable to uniformly distribute the load between said rods; and

said hydraulically-operated means including a plurality of hydraulic cylinders,

each cylinder having a reciprocating piston coupled to one of said rods, and

said pistons having substantially-equal, effective, cross-sectional areas.

2. The apparatus of claim 1 in which said hydraulically-operated means include a common fluid reservoir in fluid communication with each of said pistons.

3. The apparatus of claim **2** in which said flexible track portions are operable to assume a desired curvature for imparting said curvature to said portion of said pipeline engaged by said first tool.

4. An apparatus for operating on a relatively-inflexible movable pipeline, said apparatus including:

a first pipe-engaging tool, said tool comprising:

a first continuous chain;

a first series of spaced blocks supported by said chain,

said blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other;

each pin rotatably supports at least a pair of said rollers displaced from each other, and each roller of each of said pair of rollers forms part of a series of rollers riding on a distinct track means;

means operatively coupled with said first tool for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses, and

said track means having a substantially oval configuration.

5. An apparatus for operating on a relatively-inflexible movable pipeline, said apparatus including:

a first pipe-engaging tool, said tool comprising:

a first continuous chain;

a first series of spaced blocks supported by longitudinally-spaced chain,

said blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other;

a series of rollers on said pins, each pin rotatably supports at least a pair of said rollers displaced from each other;

first roller-support track means, said rollers being adapted to roll on said track means;

means operatively coupled with said first tool for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses;

a bottom plate;

a top plate;

means rotatably supporting said chain for rotation between said plates; and

said rotatably supporting means being positioning rollers.

6. The apparatus of claim **5** and further including: at least two rails, and end rollers coupled to said plates for riding on said rails, thereby allowing said tool to move in a direction which is generally transverse to the path of travel of said portion of said pipeline.

7. The apparatus of claim **6** and further including hydraulically-operated means coupled to said tool and effective to reciprocatingly move said tool on said rails.

8. The apparatus of claim **7** in which said tool is effective to apply a series of longitudinally-displaced, relatively-high transverse forces against said portion of said pipeline engaged by said tool thereby avoiding excessive concentrated forces.

9. An apparatus for operating on a relatively-inflexible movable pipeline, said apparatus including:

a first pipe-engaging tool, said tool comprising:

a first continuous chain;

a first series of spaced blocks supported by said chain,

said blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other;

a series of rollers on said pins;

first roller-support track means, said rollers being adapted to roll on said track means;

means operatively coupled with said first tool for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses; and

said roller-support tracks means including:

two short-radius, curved, side tracks separated by two relativelylflat, main tracks, and each of said blocks having a length sufficiently shorter than the distance between two consecutive pins in said chain, thereby allowing each support block to rapidly accelerate in the transition region between a main track and an adjacent side track.

10. The apparatus of claim 9 in which said main tracks are relatively inflexible.

11. The apparatus of claim 9 in which said main tracks are relatively flexible.

12. The apparatus of claim 9 and further including hydraulically-operated, track-separation means for controlling the slackness in said chain.

13. An apparatus for operating on a relatively-inflexible movable pipeline, said apparatus including:

a first pipe-engaging tool, said tool comprising:

a first continuous chain;

a first series of spaced blocks supported by said chain,

said blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other;

a series of rollers on said pins;

first roller-support track means, said rollers being adapted to roll on said track means;

means operatively coupled with said first tool for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses;

a second pipe-engaging tool, said second tool comprising:

a second continuous chain;

a second series of spaced blocks supported by said second chain, said second blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a second series of pins interlinking said blocks to allow said second blocks to pivotally move relative to each other;

a second series of rollers on said second pins;

second roller-support track means, said second rollers being adapted to roll on said second track means;

said second tool being operatively coupled with said first tool for maintaining and selectively moving said portion of said pipeline on said first and second blocks against their curved surfaces, thereby allowing said first and second pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses;

a third pipe-engaging tool, said third tool comprising:

a third continuous chain;

a third series of spaced blocks supported by said third chain, said third blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline;

a third series of pins interlinking said third blocks to allow said third blocks to pivotally move relative to each other;

third roller-support track means, said third rollers being adapted to roll on said third track means; and

said third tool being operatively coupled with said first tool and second tool for maintaining and selectively moving said portion of said pipeline on said first, second and third blocks against their curved surfaces, thereby allowing said first, second and third pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced stresses.

14. The apparatus of claim 13 and further including: power means operable to effectively move said tools relative to each other.

15. The apparatus of claim 14 wherein: said first and third tools are positioned on one side of the longitudinal axis of said pipeline, and said second tool is positioned between said first and third tools on the opposite side of said longitudinal axis.

16. The apparatus of claim 15 wherein: said first roller-support track means has a constant curvature thereby imparting to said portion of said pipeline said constant curvature.

17. The apparatus of claim 16 in which said portion of said pipeline sustains a change in curvature as it moves from said first tool toward said second tool.

18. The apparatus of claim 17 in which: said first, second and third pipe-engaging tools are effective to substantially straighten said portion of said pipeline.

19. The apparatus of claim 18 and further including torque producing means for rotating said second and third chains.

20. The apparatus of claim 19 in which: each of first, second and third blocks includes a removably-mounted flexible insert defining said curved surface for engagement with said portion of said pipeline.

21. The apparatus of claim 18 in which: said second and third roller-support track means include track portions which are relatively flexible, said flexible track portions supporting the rollers which are associated with said pipe-engaging blocks, and further including: hydraulically-operated means comprising longitudinally-displaced support rods for supporting said flexible track portions.

22. The apparatus of claim 21 and further including tensioning means to effectively exert tensioning forces in said portion of said pipeline, while said portion of said pipeline moves through said first, second and third tools.

23. The apparatus of claim 21 wherein said second and third support rods provide substantially uniform support to said portion of said pipeline engaged by the respective tools.

24. The apparatus of claim 23 in which said support rods are automatically and reciprocatingly movable to uniformly distribute the load between said rods.

25. The apparatus of claim 24 in which said hydraulically-operated means include hydraulic cylinders,

each cylinder having a reciprocating piston coupled to one of said rods, and

said pistons having substantially equal effective cross-sectional areas.

26. The apparatus of claim 25 in which said hydraulically-operated means include a common fluid reservoir in fluid communication with each of said pistons.

27. The apparatus of claim 26 in which said flexible track portions in said second and third tools are each operable to assume a distinct desired curvature for imparting said curvature to said portion of said pipeline engaged by said second and third tools.

28. The apparatus of claim 27 wherein each pin rotatably supports at least a pair of said rollers displaced from each other.

29. The apparatus of claim 28 wherein each of said second and third track means has a substantially oval configuration.

30. The apparatus of claim 22 wherein:

said first, second and third tools, and said tensioning means are mounted on a platform, and further including power means to selectively and reciprocatingly move said platform in a vertical direction.

31. The apparatus of claim 29 wherein the amount of movement of said second tool relative to said first and third tools determines the amount of curvature imparted to or removed from said pipe during the pipe passage through said tools.

32. The apparatus of claim 31 wherein said pipeline is advanced generally along a longitudinal direction and in which:

successive portions of the advancing pipe are subjected first to initial transverse bending forces to stress such portions above the pipe's elastic limit in one direction, and

thereafter to opposite transverse bending forces to stress such portions beyond the elastic limit in an opposite direction, thereby substantially straightening said portion of said pipeline.

33. An apparatus for laying a pipeline on a marine bottom, said apparatus comprising:

a floating platform,

a reel rotatably-mounted on said platform for supporting said pipeline,

winding and unwinding means including:

at least three continuous chains, each chain having a series of spaced blocks, said blocks having curved surfaces operable to engage

longitudinally-spaced segments of a portion of the winding and unwinding pipeline;

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other,

power means for controllably moving at least one of said chains;

two of said chains being adapted to directly engage one side of a portion of said pipeline, and

one of said chains being disposed on the opposite side of said pipeline so as to compressively engage said portion of said pipeline and to exert a series of longitudinally spaced continuously effective bending and counter-bending forces on said portion of said pipeline as it is being wound on and unwound from said reel.

34. An apparatus for straightening a long line of elasto-plastic metal pipe wound onto a coil mounted on a reel including:

first means for winding and unwinding the pipeline on and from the reel,

second means for plastically reverse-bending the pipe to a constant curvilinear configuration as it is being wound and unwound,

third means for subsequently plastically reverse-bending the pipe to a desired configuration after said pipe acquires said curvilinear configuration, and

said second means comprising:

a first continuous chain,

a first series of spaced blocks supported by said chain,

said blocks having curved surfaces operable to engaged longitudinally-spaced segments of a portion of said pipeline,

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other,

a series of rollers on said pins,

roller-support track means, said rollers being adapted to roll on said track means, and

said third means being operatively coupled with said second means for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced operating forces.

35. The apparatus of claim 34 wherein said desired configuration is substantially rectilinear.

36. The apparatus of claim 35 and further including:

means for maintaining said pipe under tension during said winding and unwinding operations.

37. The apparatus of claim 36 and further including:

means for movably supporting said rectilinear portion of said pipeline at spaced positions in a vertical plane, and

said positions being adjustable to allow said pipeline to assume a progressively decreasing elevation and to enter into a body of water along a downwardly directed path.

38. An apparatus for handling a relatively-inflexible metal pipeline, said apparatus including:

a reel rotatable about its axis;

means for rotating said reel in opposite directions for respectively winding pipe thereon and unwinding pipe therefrom;

combined bending and level wind means mounted adjacent said reel, said means comprising:

three movable chain assemblies,

each assembly being mounted for rotation about an axis extending substantially parallel to the axis of said reel,

each pair of chains being at opposite sides of the line of travel of said pipeline,

each of said chains comprising:

a series of spaced blocks supported by said chain,

said blocks having curved surfaces operable to engage longitudinally-spaced segments of a portion of said pipeline,

a series of pins interlinking said blocks to allow said blocks to pivotally move relative to each other,

a series of rollers on said pins,

roller-support track means, said rollers being adapted to roll on said track means, and means operatively coupled with said chains for maintaining and selectively moving said portion of said pipeline on said blocks against their curved surfaces, thereby allowing the pipe-engaging blocks to exert on the engaged portion of said pipeline a series of longitudinally-spaced operating forces while said pipeline is being wound and unwound on and from said reel.

39. The apratus of claim **14** and further including:

power means operable to effectively move said first and second tools closer together or further apart depending on the strength of the desired tensioning forces, and

said first and second chains are adapted to directly engage opposite sides of a generally straight portion of said pipeline so as to compress said pipeline and to exert a series of longitudinally-spaced, continuously-effective tensioning forces on said opposite sides of said straight portion of said pipeline.

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