United States Patent [19]

Clavin et al.

[11] **3,834,210**

[45] **Sept. 10, 1974**

[54] **PIPE BENDING SYSTEM**

[75] Inventors: **Edward A. Clavin; Lionel H. Wheeler,** both of Houston, Tex.; **Robert E. Brooks, Jr.; Wallace Clealon Campbell, Jr.,** both of Tulsa, Okla.

[73] Assignee: **CRC-Crose International, Inc.,** Houston, Tex.

[22] Filed: **June 6, 1972**

[21] Appl. No.: **260,275**

[52] **U.S. Cl.** **72/308,** 72/369, 72/388, 72/466

[51] **Int. Cl.** **B21d 9/05**

[58] **Field of Search** 72/125, 308, 309, 310, 72/380, 388, 398, 465, 466, 369, 296

[56] **References Cited**

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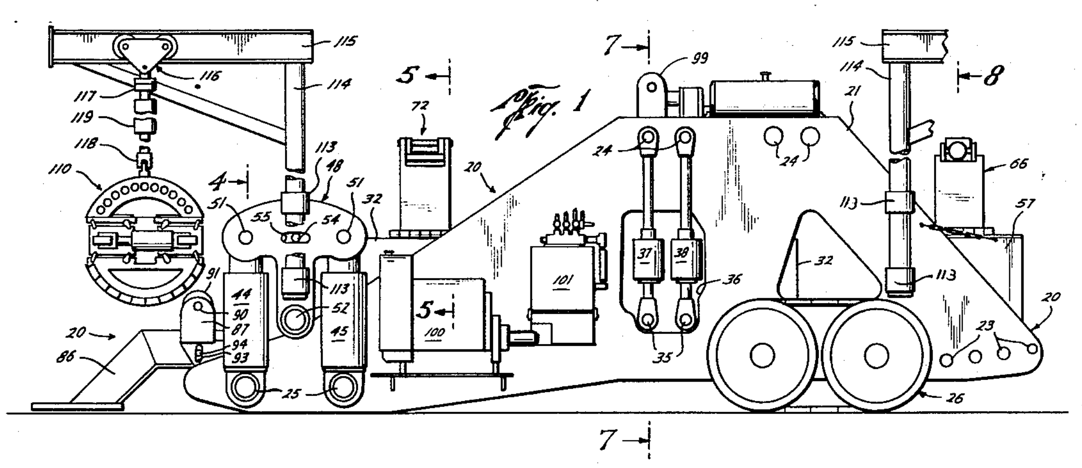
Primary Examiner—Lowell A. Larson
Attorney, Agent, or Firm—Joe E. Edwards

[57] **ABSTRACT**

An improved pipe bending system including a pipe bending machine and an internal pipe supporting mandrel. The pipe bending machine comprises a main frame having connected thereto directly or indirectly a bending die, a stiffback, and a stiffback clamp, a pin-up shoe and a pin-up clamp, an internal stiffback support, and an internal pin-up support. The internal pipe supporting mandrel includes an upper assembly having a plurality of elongated inflatable bags attached thereto, a lower assembly, and means connecting the upper and lower assembly for moving them apart and into engagement with the interior of the pipe. This abstract is neither intended to define the invention of the application which, of course, is measured by the claims, nor is it intended to be limiting as to the scope of the invention in any way.

22 Claims, 23 Drawing Figures



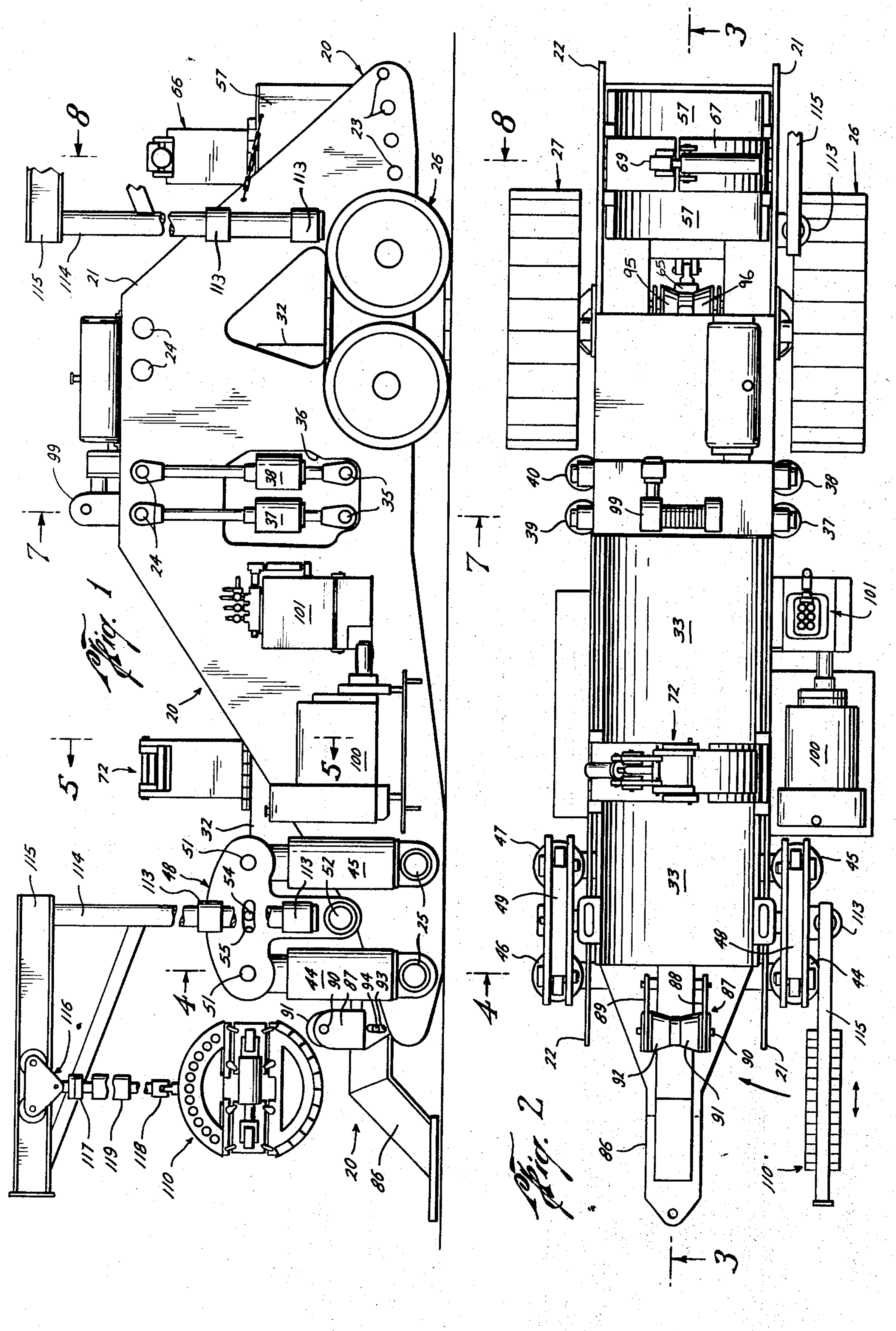


Fig. 1
Fig. 2

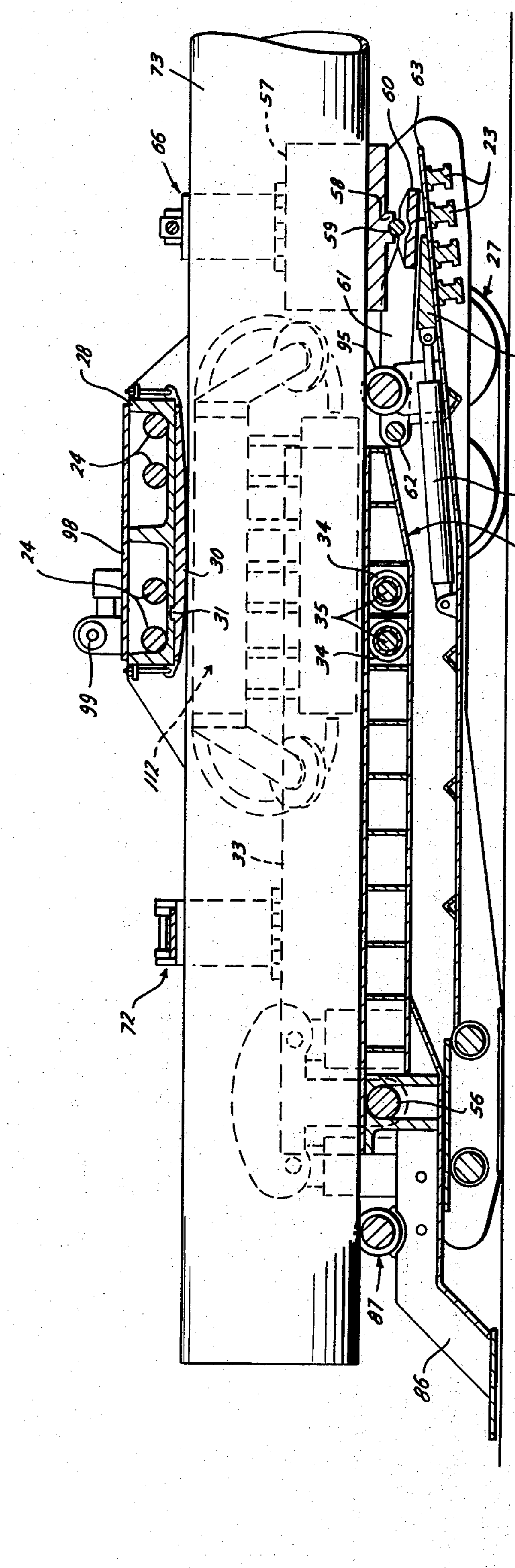

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Fig. 3

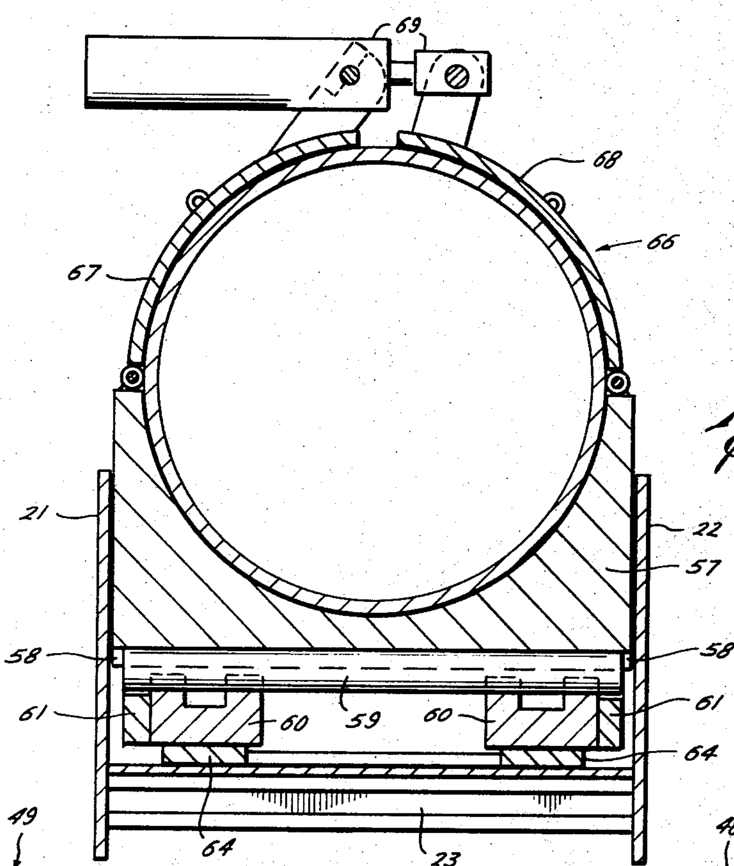
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Fig. 8

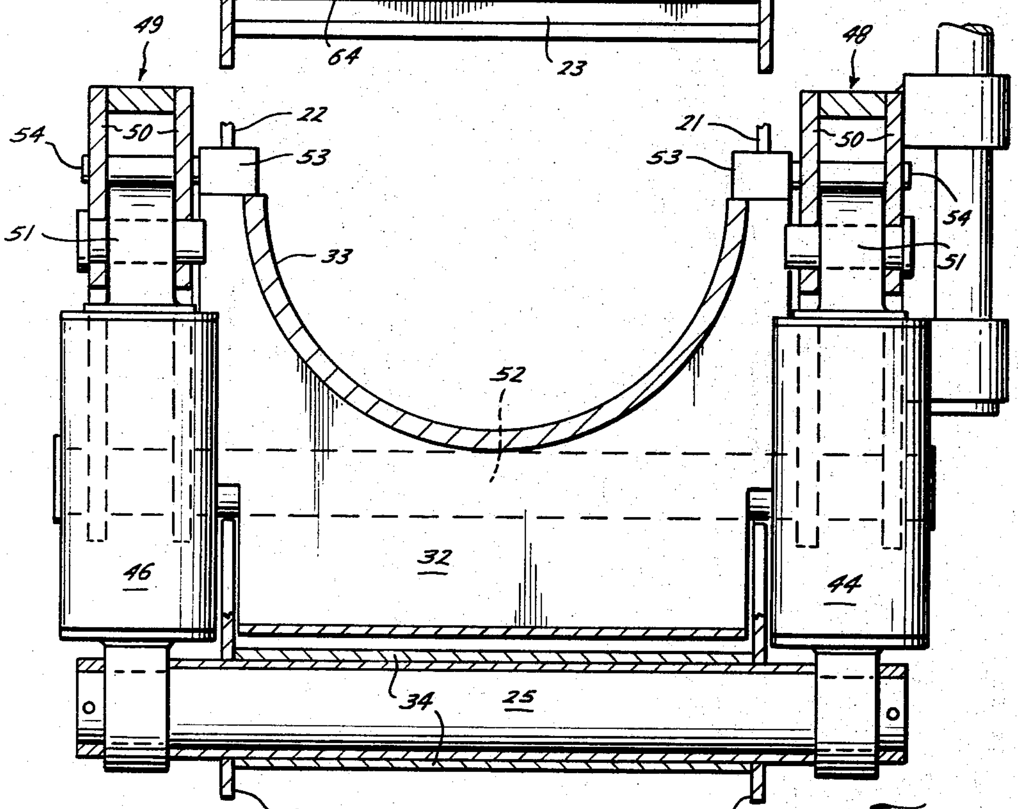
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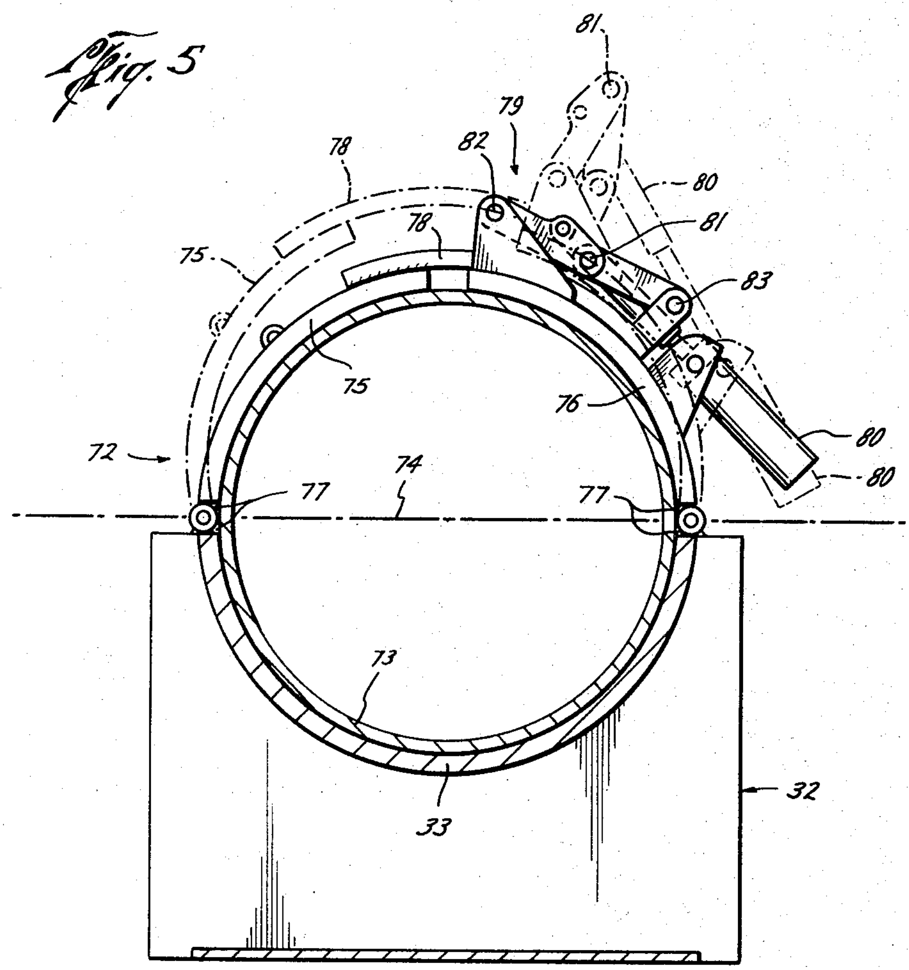
Fig. 4

Fig. 5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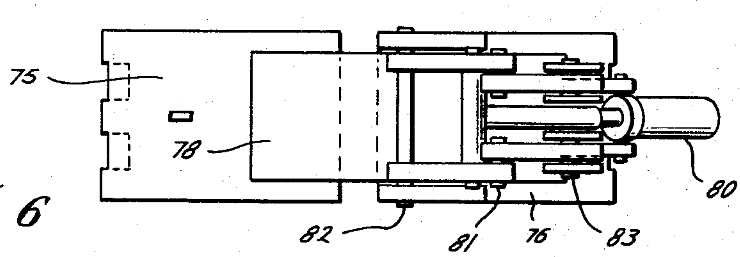
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Fig. 6

Fig. 7

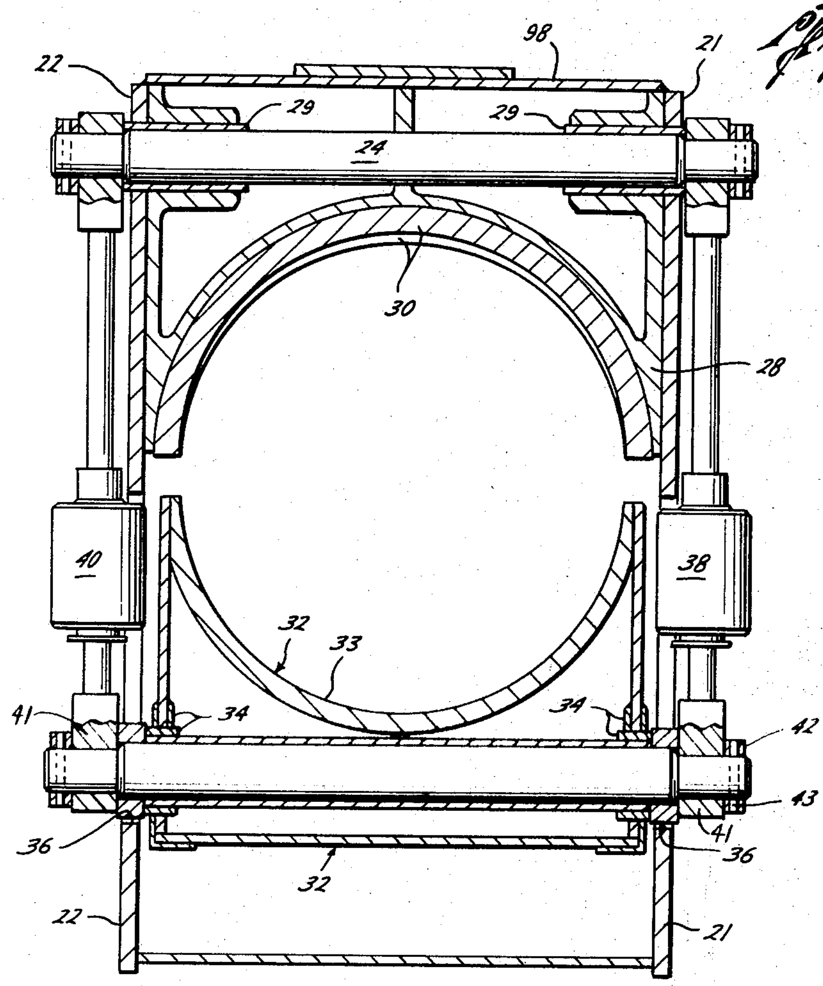
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Fig. 9

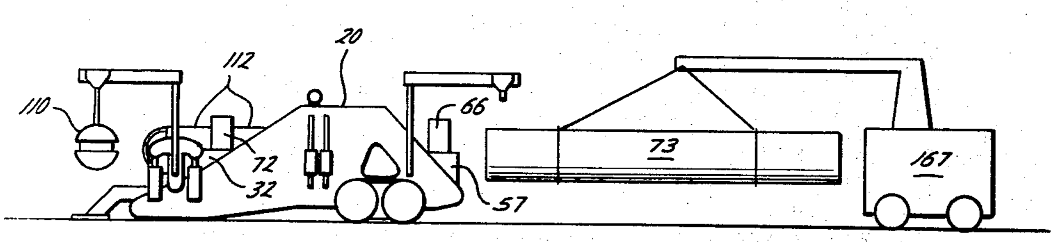
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Fig. 10

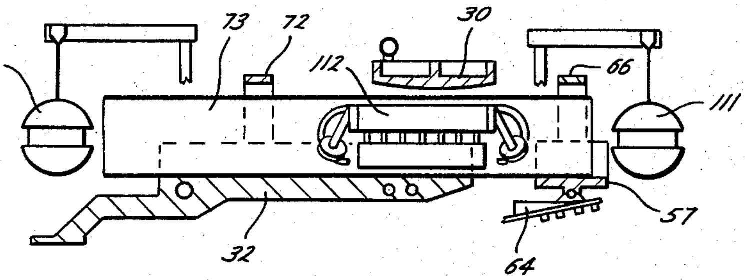


Fig. 11

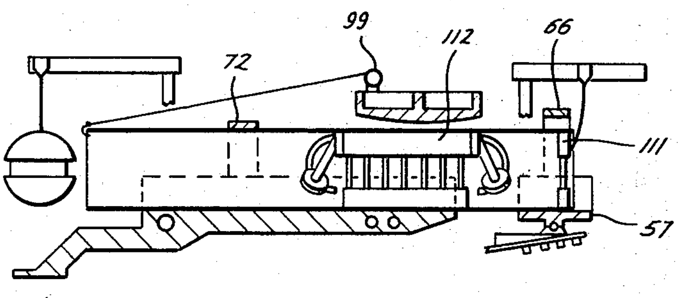


Fig. 12

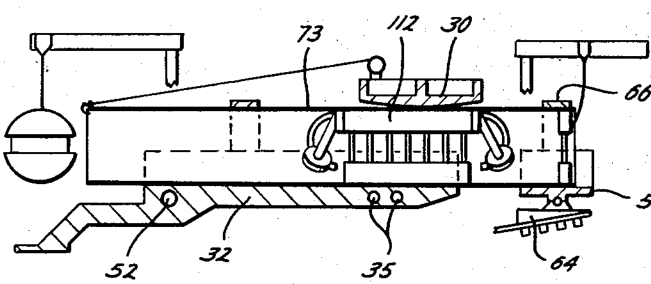


Fig. 13

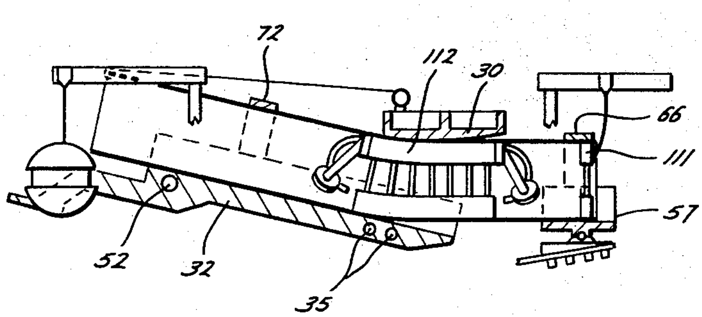
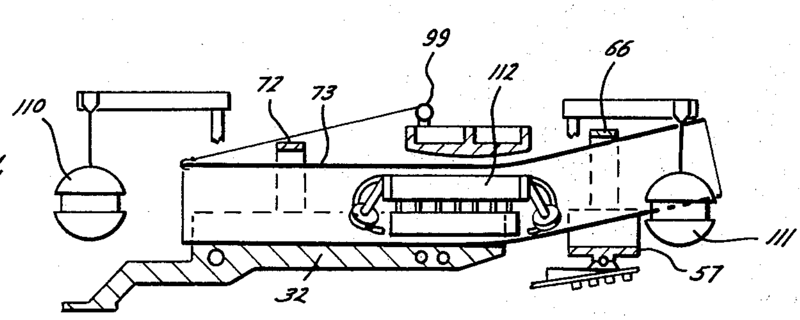


Fig. 14



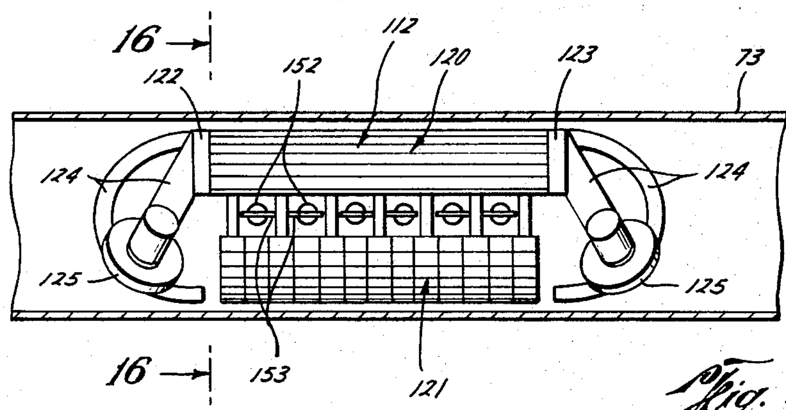

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Fig. 15

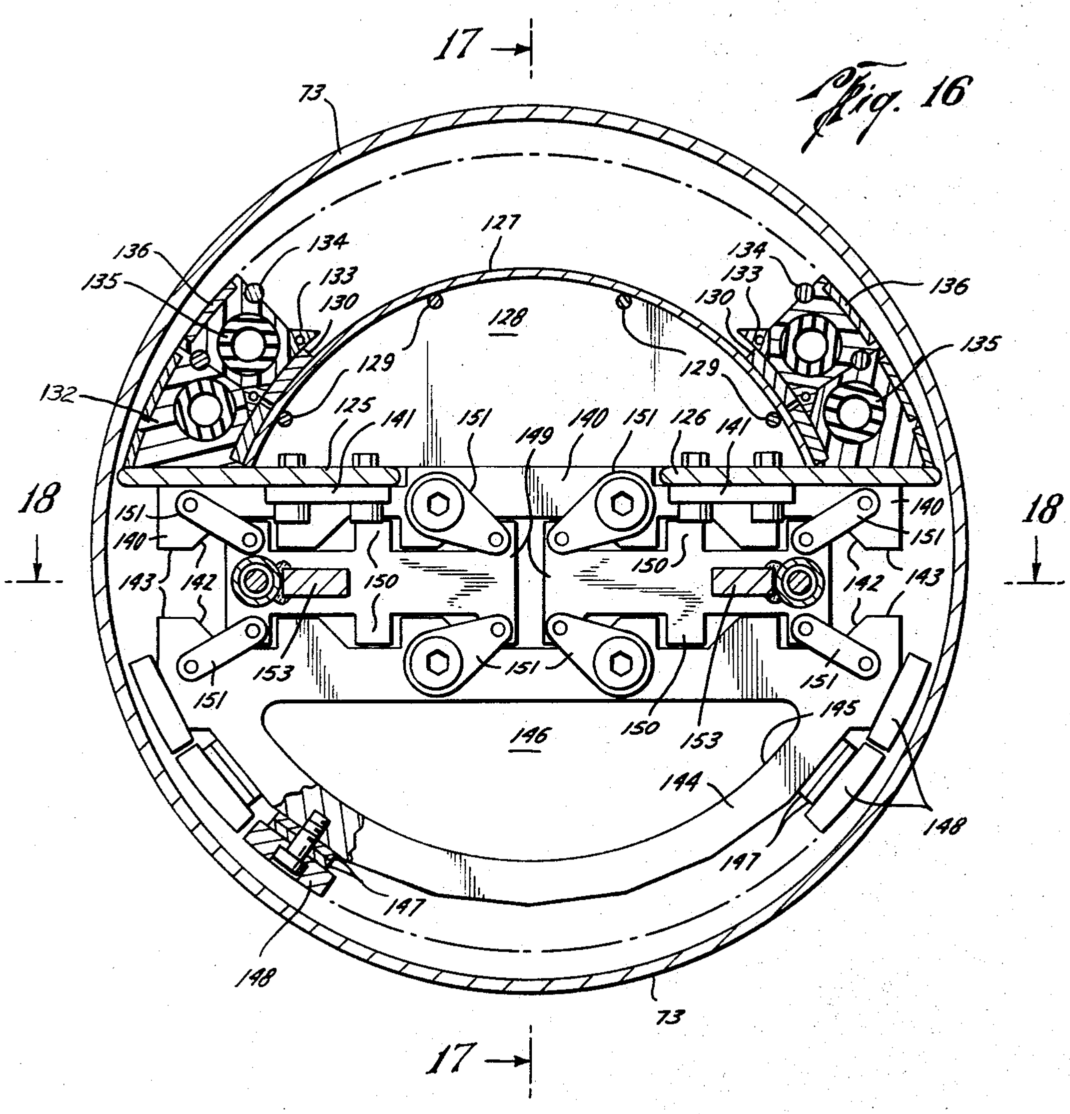
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Fig. 16

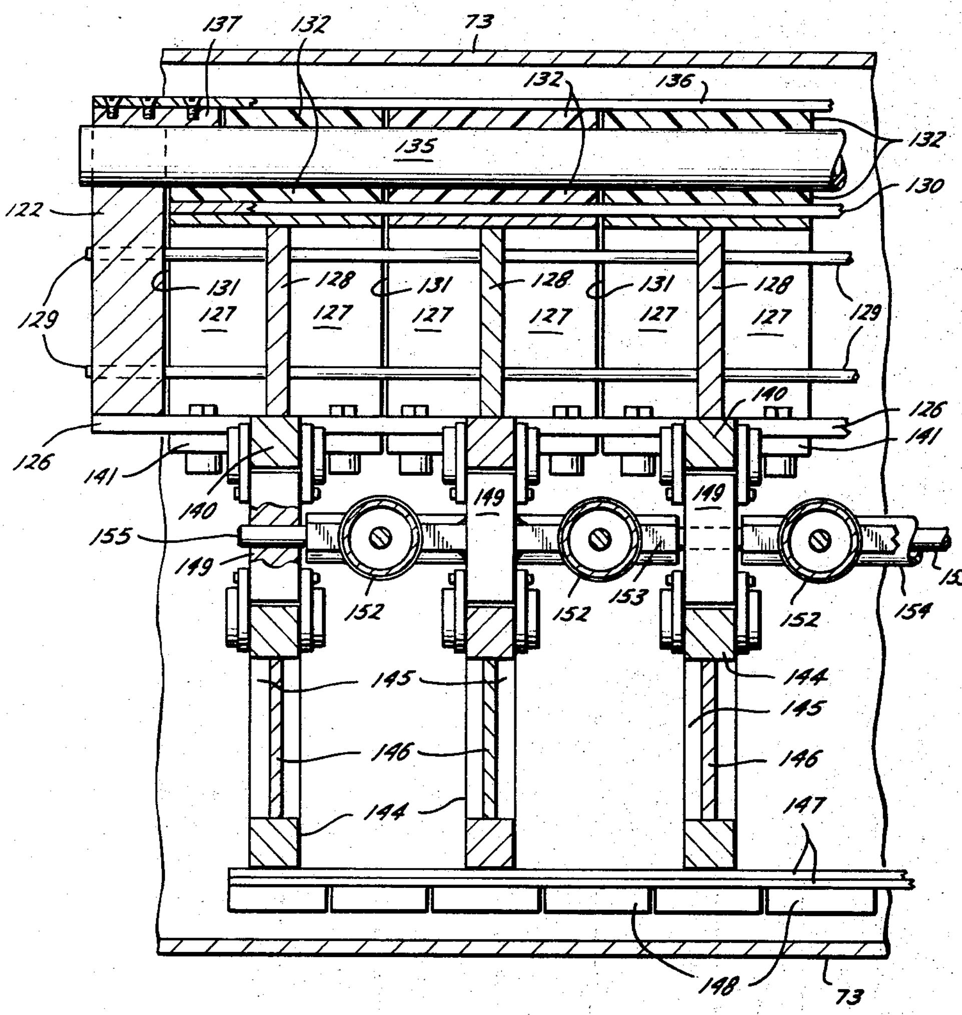
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Fig. 17

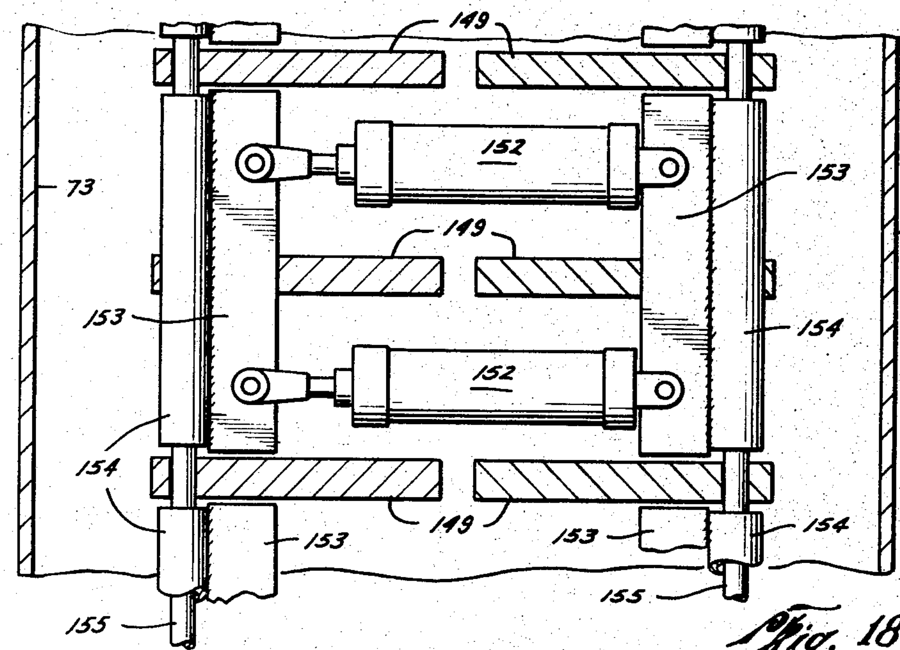
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Fig. 18

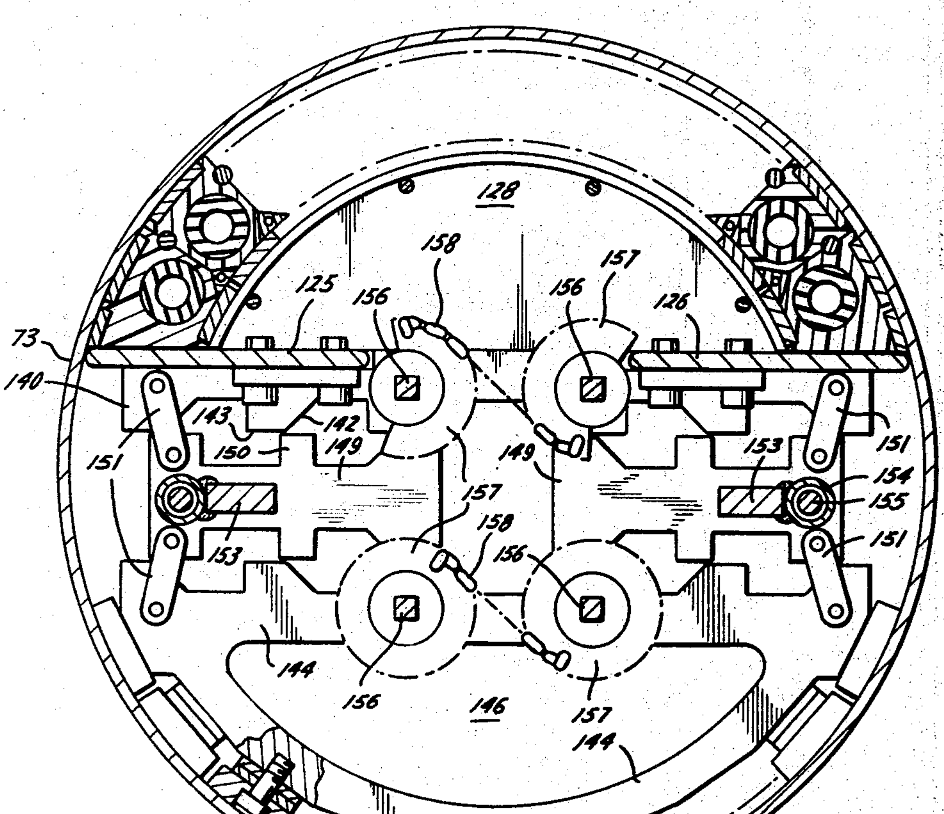
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Fig. 19

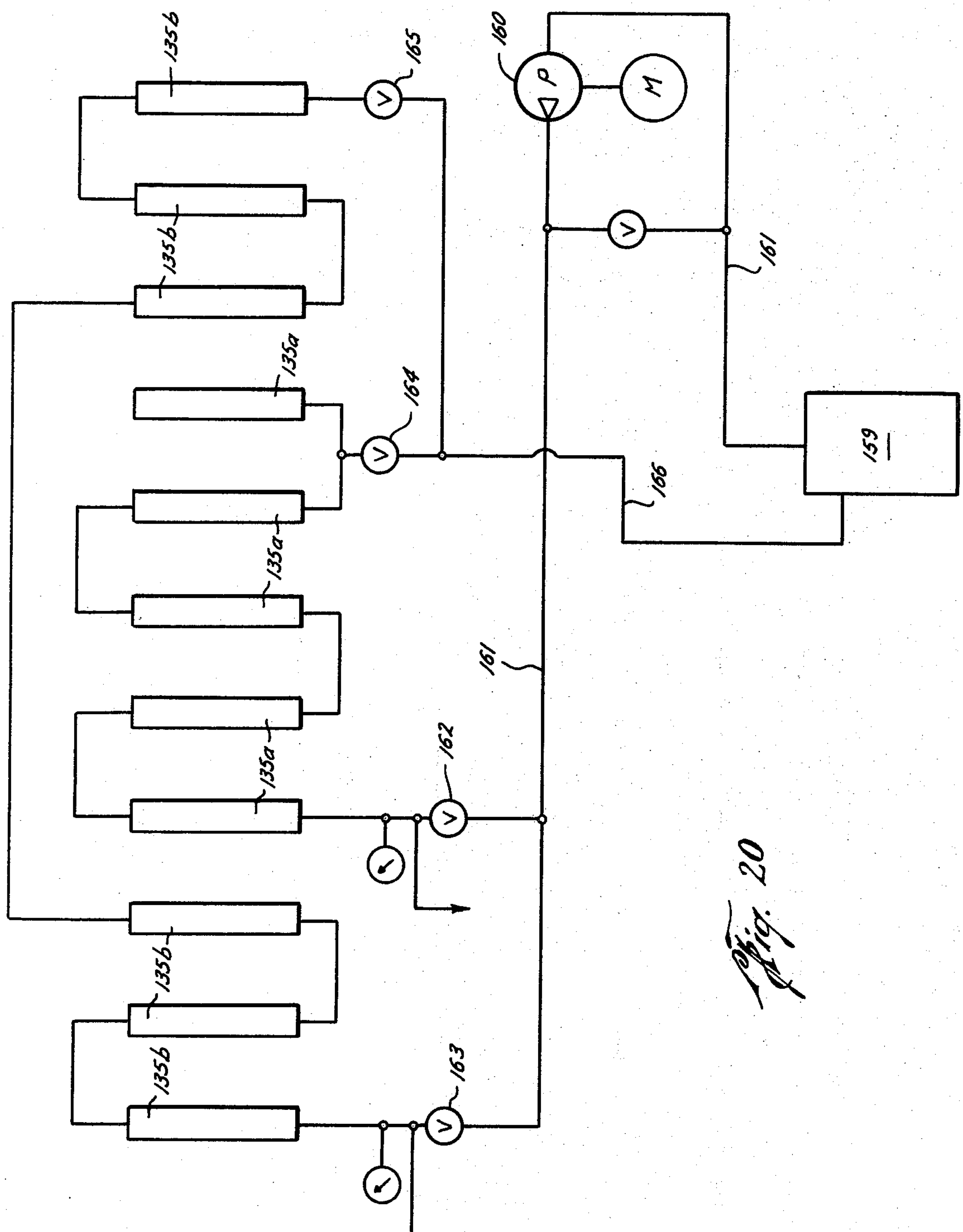

Fig. 20

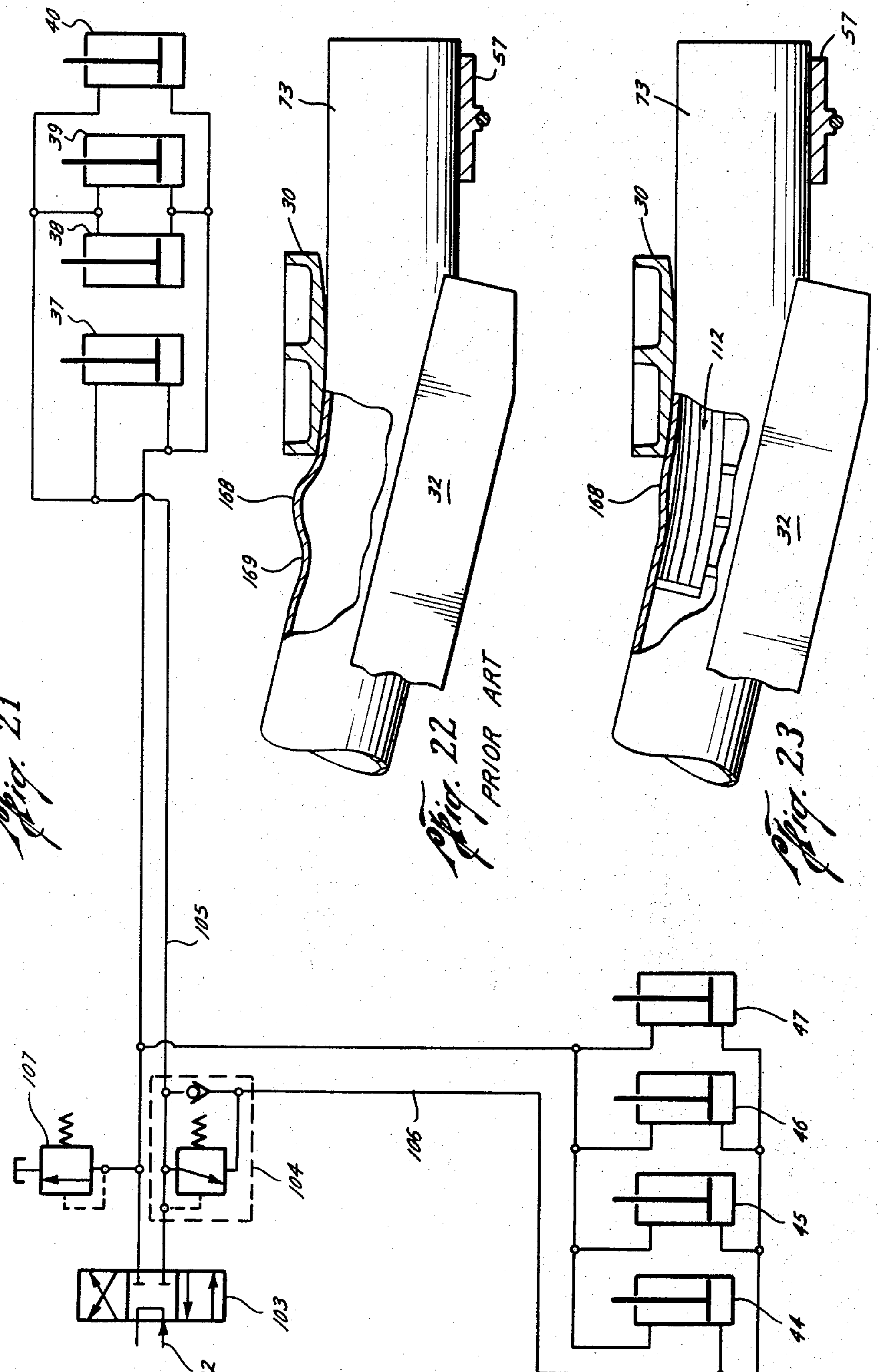

Fig. 21

Fig. 22 PRIOR ART

Fig. 23

PIPE BENDING SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to the cold bending of metallic pipe such as constitutes the end-to-end joint sections in a cross-country pipeline. More particularly, this invention relates to a bending meachine and internal support mandrel capable of operating on currently favored thin wall, high strength alloy, large diameter pipe.

There exist today numerous machines for the bending of pipe, including those machines taught in U.S. Pat. Nos. 2,347,593; 2,428,764; 2,500,980; 2,589,651; 2,708,471; 2,740,452; 2,740,453, 2,771,116; 2,970,633; 3,014,518; and 3,335,588. Additionally, ghere exist numerous internal support mandrels capable of being utilized with pipe bending machines, including those taught in U.S. Pat. Nos. 2,401,052; 2,984,284; 3,014,518; 3,043,361; 3,109,477; and 3,180,130. Each of these bending machines and internal support mandrels functions excellently to bend pipe. This invention, however, provides an improved pipe bending system, including an improved pipe bending machine and an improved internal support mandrel, having advantages over the prior art.

It is an object of this invention to provide an improved self-contained pipe bending system of relatively small bulk, both transversely and vertically, and of minimum weight for ease of transit.

It is an object of this invention to provide a self-contained pipe bending system which may be utilized to bend pipe in rough terrain.

It is an object of this invention to provide a pipe bending system which imparts an improved bend to thin wall, high strength alloy, large diameter pipe, including more accuracy in the degrees of bend, less deformity in the circular shape of the pipe, and fewer wrinkles in the skin of the pipe.

It is an object of this invention to provide a pipe bending system which imparts to the pipe a bend of shorter radius than that imparted by existing systems.

It is an object of this invention to provide a pipe bending system in which the bend may be imparted to the pipe closer to the end of the pipe than with previously existing systems and thus allows more bend to be imparted to a segment of pipe.

It is an object of this invention to provide a pipe bending system having an improved internal support mandrel which is capable of expanding more rapidly and providing greater support than previously existing mandrels.

It is a further object of this invention to provide a pipe bending system having an improved internal support mandrel capable of accurately directing its support forces whereby the shape of the pipe may be affirmatively controlled.

The invention itself, both as to organization and method of operation, as well as additional objects and advantages thereof, will become readily apparent from the following description when read in connection with the accompanying drawings, in which like numerals represent like parts:

FIG. **1** is a side elevation view of the preferred pipe bending machine of the improved pipe bending system of this invention; the internal support mandrel is not shown.

FIG. **2** is a plan view of the preferred pipe bending machine illustrated in FIG. **1.**

FIG. **3** is a schematic sectional view of the preferred pipe bending machine taken at lines **3—3** in FIG. **2** with a schematic illustration of the preferred internal support mandrel added thereto.

FIG. **4** is a sectional view of the outer stiffback support assemblies and the stiffback of the preferred pipe bending machine taken at lines **4—4** in FIG. **1.**

FIG. **5** is a sectional view of the stiffback clamp of the preferred pipe bending machine taken at lines **5—5** in FIG. **1.**

FIG. **6** is a plan view of the stiffback clamp illustrated in FIG. **5.**

FIG. **7** is a sectional view of the inboard stiffback cylinder and piston assemblies, the die support, the bending die, and the stiffback of the preferred pipe bending machine taken at line **7—7** in FIG. **1.**

FIG. **8** is a sectional view of the pin-up clamp, pin-up shoe and wedge of the preferred pipe bending machine taken at lines **8—8** in FIG. **1.**

FIGS. **9–14** are a series of schematic views of the preferred pipe bending system according to this invention illustrating the preferred method of bending pipe according to this invention.

FIG. **15** is a schematic side elevation view of a preferred internal support mandrel according to this invention positioned in its collapsed condition inside a pipe.

FIG. **16** is a detail sectional view of the preferred internal support mandrel taken at lines **16—16** in FIG. **15.**

FIG. **17** is a detail sectional view of the preferred internal support mandrel taken at lines **17—17** in FIG. **16.**

FIG. **18** is a detail sectional view of the preferred internal support mandrel taken at lines **18—18** in FIG. **16.**

FIG. **19** is a detail sectional view of the preferred internal support mandrel also taken at lines **16—16** in FIG. **15** with the mandrel in its expanded condition and with movement compensators added to certain of the mechanical linkages.

FIG. **20** is a schematic view of certain components of the preferred hydraulic connections between the inflatable bags attached to the upper assembly of the preferred internal support mandrel.

FIG. **21** is a schematic view of certain components of the preferred hydraulic connections between the outboard and inboard stiffback cylinder and piston assemblies of the preferred pipe bending machine.

FIGS. **22** and **23** are schematic illustrations of the prior art bending of pipe and the bending of pipe according to this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The improved, self-contained, portable pipe bending system according to this invention, which is capable of accurately bending thin wall, large diameter pipe, includes a pipe bending machine and an internal pipe supporting mandrel. A preferred pipe bending machine **20** according to this invention is illustrated in side elevation in FIG. **1** and in plan in FIG. **2.** The pipe bending machine **20** preferably comprises a heavy-duty main frame to which is attached directly or indirectly the other components of this pipe bending system. The improved internal pipe supporting mandrel, not shown in FIGS. **1** and **2**, rests within a component attached to the main frame as will hereinafter be explained.

The main frame of the pipe bending machine preferably comprises two heavy-duty, metallic, planar side frames **21** and **22** secured to each other by a plurality of stout crossmembers or transverse beams **23, 24** and **25.** Each of the side frames **21** and **22** preferably is of unitary construction with cavities or holes cut therein at low-stress points to reduce the weight and to facilitate the movement of certain cylinder and piston assemblies as will hereinafter be explained. The ends of each of the transverse beams **23, 24** and **25** not only are welded to the side frames, but in order to strengthen the pipe bending machine, also extend through holes cut in the side frames **21** and **22.** The side frames and the transverse beams produce a main frame which, when viewed from the end, presents an open, rectangular framework into which the pipe to be bent may be inserted.

To facilitate describing this invention, the end of the preferred pipe bending machine into and out of which the pipe is moved (the rear of the machine or the end on the right of the machine as viewed in FIG. **1**) shall be referred to as the "pin-up" end; the other end of the machine shall be referred to as the "stiffback" end.

Secured to each of the side frames **21** and **22** at contractible positions relatively near the pin-up end of the machine is a set of Athey tracks or an endless track assembly **26** and **27**, respectively, such as is well known to those skilled in the art. The bottoms of side frames **21** and **22** preferably are cut so they are off the ground at the pin-up end of the machine and rest on the ground at the stiffback end of the machine. Thus, when the pipe bending machine is in position to bend pipe, the four points in contact with the earth will be the two sets of Athey tracks **26** and **27** and the bottoms of the side frames **21** and **22** at the stiffback end of the machine.

Referring now to FIGS. **1, 2, 3** and **7,** there is mounted within the top of the main frame a die support **28.** Die support **28** preferably is a cast iron shell constructed to present a downwardly facing supporting surface to receive the die against which the pipe is to be bent. Die support **28** is secured within the main frame by journaling the four transverse beams **24** through reinforcing receiving rings **29** mounted in holes cut in the sides of the die support. The bending die **30** comprises an elongated metallic plate which fits into the downwardly facing cavity of die support **28.** Preferably there is a pin **31** protruding upwardly from the metal plate of the die **30** into a receiving hole in die support **28** which functions to lock the die into a fixed relationship with the die support. The die **30** is removably secured within die support **28** by bolting together lugs extending from both of the members. The metal plate of die **30** presents a downwardly facing surface that is concave in transverse section and convex in longitudinal section on the arcuate path to which the pipe will conform during bending. The portions of the die surface which engage the pipe during bending preferably have attached thereto replaceable resilient linings such as are disclosed in the prior copending application of Edward A. Clavin and Lionel H. Wheeler, Ser. No. 236,879, filed Mar. 22, 1972.

Also mounted within the main frame of the bending machine is an elongated holding shoe or stiffback **32** for holding the pipe. Stiffback **32** is a relatively long metallic element presenting an upwardly facing pipe engaging cavity which is nearly semicircular in transverse section throughout its length. As particularly illustrated in FIGS. **2** and **3**, stiffback **32** extends from a plane near the stiffback end of the machine to a plane adjacent the end of the bending die **30** nearest the pin-up end of the machine. The stiffback **32** is comprised of a metallic framework supporting an elongated, transversely concave heavy-duty metallic plate **33.** To further facilitate description of this invention, the end of the stiffback **32** positioned adjacent the stiffback end of the machine shall be referred to as the outboard or outer end of the stiffback; the other end of the stiffback **32** shall be referred to as the inboard or inner end.

Secured within the framework of the stiffback **32** at selected positions adjacent its inner end are two pairs of reinforcing rings **34** for receiving two transverse, inboard stiffback shafts **35.** The ends of the two transverse shafts **35** protrude through a cavity **36** cut in each of the side frames **21** and **22** far enough to have inboard stiffback cylinder and piston assemblies secured thereto. There are two inboard stiffback cylinder and piston assemblies on each side of the main frame. Each of these cylinder and piston assemblies **37, 38, 39** and **40** is secured by ordinary means between a protruding end of one of the transverse beams **24** supporting die support **28** and an end of one of the inboard stiffback shafts **35.** Preferably each of the beams **24** and shafts **35** extends through a flange **41** attached to the cylinder and piston assembly and is secured thereto with a collar **42** and pin **43.**

The pair of transverse beams **25** welded to side frames **21** and **22** adjacent the stiffback end of the machine extend through the side frames sufficiently to provide support for a pair of outboard cylinder and piston assemblies **44** & **45** and **46** & **47** on each side of the main frame. Each of these pairs of outboard cylinder and piston assemblies **44** & **45** and **46** & **47** is secured by ordinary means between the two transverse beams protruding on its side of the main frame and an outer stiffback support assembly **48** and **49,** respectively. As shown particularly in FIGS. **1, 2** and **4,** each of the outer stiffback support assemblies **48** and **49** is comprised of two stout, parallel T-bar plates **50** joined together. The cylinder and piston assemblies are secured to the outer stiffback support assemblies by pins **51** extending through the plates. Each of the T-bar plates comprising the support assemblies **48** and **49** includes a leg which extends downwardly between the two cylinder and piston assemblies attached to the particular support assembly. Mounted within the stiffback framework is a reinforcing ring (not shown) through which is journaled a transverse outboard stiffback shaft **52.** Outboard stiffback shaft **52** protrudes beyond the stiffback frame on each side thereof a sufficient distance to extend through and be secured to the downwardly extending legs of the two outer stiffback support assemblies **48** and **49.** Secured to the top of the stiffback frame on each side thereof adjacent the middle of the outer stiffback support assemblies **48** and **49** are metallic blocks **53** each of which supports a laterally extending pin **54.** Each of the pins **54** extends through an elongated traveling slot **55** in the adjacent outer stiffback support assembly and thus functions as a guide pin during the upward movement of the stiffback **32.**

Referring particularly to FIGS. **1, 3** and **8,** there is a pin-up shoe **57** in the main frame adjacent the pin-up end of the machine and spaced from the end of the bending die **30.** The pin-up shoe **57** is a relatively short metallic member providing an upwardly facing pipe-engaging surface which is nearly semicircular in transverse section throughout its length. Depending from the underside of the pin-up shoe is a transverse flange **58** in which is rotatably mounted a transverse pin **59.** The transverse pin **59** rotatably rests on a pair of rocking elements **60** (shown in FIG. **3** detached from the pin). Each of the rocking elements **60** is attached to an arm **61** which is rotatably secured by a pin **62** to the main frame near the inner end of the stiffback **32.** Longitudinally slidable between a supporting plate **63** secured to the transverse beams **23** and the rocking elements **60** is a pair of interconnected wedges **64.** The pair of wedges **64** is affirmatively moved longitudinally in both directions by a cylinder and piston assembly **65** pinned to the main frame. Thus, the pin-up shoe **57** is mounted for movement in the vertical arc transcribed by the pin **59** moving about pin **62** responsive to the movement of the wedges **64.** Moreover, pin-up shoe **57** is mounted for rotation about pin **59** to conform to the longitudinal slope of the pipe held therein.

It can now be observed that the preferred pipe bending machine according to this invention bends pipe by securing it between the cooperating bending die **30,** stiffback **32** and pin-up shoe **57.** A length of pipe inserted in the stiffback **32** and pin-up shoe **57** as illustrated in FIG. **3** is bent about the bending die **30** by moving the outboard end of stiffback **32** upwardly. The inboard stiffback shafts **35** conjunctively act as a pivot for the stiffback **32.** Pin-up shoe **57** acts as the fulcrum or support means for the rearward end of the pipe to prevent it from moving downward.

Secured to the pin-up shoe is a pin-up clamp **66** which functions to provide full circular support for the pipe contained in the pin-up shoe **57.** However, since most of the forces generated by the portion of the pipe in the area of the pin-up shoe during bending are downward against the pin-up shoe **57** and there is little tendency for the pipe to "egg" out laterally in this area, the pin-up clamp **66** does not have to be constructed of great strength. FIG. **8** illustrates a preferred pin-up clamp **66** comprising two semicircular arcuate plates **67** and **68** hinged to the top edges of the sides of the pin-up shoe. The opposing ends of the two plates **67** and **68** are joined together with a cylinder and piston assembly **69.**

It has been found that the mere combination of the bending die **30** and the stiffback **32** is not sufficient to bend properly large diameter, thin-wall pipe. Due to the enormous forces generated during bending, the pipe tends to bulge or "egg" out laterally at points along its length which are supported by the stiffback. Accordingly, as illustrated in FIGS. **1, 2, 3, 5** and **6,** in the preferred embodiment of this invention, there is secured to stiffback **32** a stiffback clamp **72** which functions conjunctively with stiffback **32** to provide full circular support for the exterior of the pipe **73** longitudinally of the die **30** during bending. Stiffback clamp **72** preferably is comprised of two arcuate metallic plates **75** and **76** securely hinged to the stiffback **32.** The space around each of the hinges between the arcuate plates **75** and **76** and the top of the stiffback, preferably is filled with a weld **77** so the pipe cannot wrinke out. Welded or otherwise connected to arcuate plate **75** is an arcuate connecting plate **78.** Arcuate connecting plate **78** is slidable over the outside circumference of arcuate plate **76** and is secured to plate **76** through a locking toggle mechanism **79** well known to those skilled in the art. Locking toggle mechanism **79** is hydraulically operated by cylinder and piston assembly **80.** FIG. **5** illustrates the stiffback clamp **72** in its open position with dashed lines. Contraction of the hydraulic cylinder and piston assembly **80** causes the stiffback clamp **72** to assume its closed position shown drawn with solid lines. When the pivot point **81** of the locking toggle mechanism has crossed the centerline between the pivots **82** and **83,** the stiffback clamp **72** is mechanically "locked" into closed position.

In the preferred embodiment of this invention, the stiffback **32** does not provide a full semicircle of support. Rather, to facilitate movement of a pipe **73** into, along and out of the stiffback **32,** as illustrated in FIG. **5,** the sides of the stiffback **32** do not quite reach up to the horizontal centerline **74** of the pipe **73** held therein. The stiffback clamp **72** and, as illustrated in FIGS. **7** and **8,** the bending die **30** and the pin-up clamp **66** provide the remainder of the required circular exterior support for the pipe **73** during bending.

The stiffback clamp **72** preferably is located as close as possible to the outboard end of the bending die **30.** In the preferred embodiment of this invention, the stiffback clamp **72** is illustrated positioned close enough to the bending die **30** to provide the needed support but far enough away to allow the bending die **30** to be removed from within the die support **28** and a new bending die **30** substituted therefor.

The construction of the stiffback clamp **72** is, of course, not limited to that described herein. Numerous forms of rugged, strong clamps may be used to provide the needed exterior support for the pipe. Also, the stiffback **32** itself may be constructed to be more fully circular to provide additional exterior support for the pipe.

Secured to the outboard end of the stiffback assembly **32** is a tongue assembly **86.** Tongue assembly **86** provides a means by which the entire bending machine may be grasped by a tractor or the like and towed to preselected positions. Secured to the tongue assembly **86** adjacent the stiffback end of the main frame is a roller support assembly **86.** Roller support assembly **87** functions to lift the pipe slightly from the stiffback **32** when the stiffback **32** and the tongue assembly **86** are at their lowest position. This facilitates easy movement of the pipe longitudinally through the main frame. Roller support assembly **87** preferably comprises two T-shaped flanges **88** and **89,** each of which is pivotally secured to opposite sides of the tongue assembly **87.** Secured between the two T-shaped flanges **88** and **89** is a transverse shaft **90** which supports conically shaped rollers **91** and **92.** Each of the T-shaped flanges **88** and **89** has a receiving slot **93** cut therein to receive a pin **94** protruding from the side of tongue assembly **87.** Secured to the inside of each of side-frames **21** and **22** is a horizontal plate (not shown). The plate is positioned and the T-shaped flanges are shaped so that when the stiffback assembly **32** and its attendant tongue assembly **87** are in their lowest position, the roller support assembly **87** has contacted the plate and has moved upwardly — thereby lifting rollers **91** and **92.** When the stiffback assembly **32** and tongue assembly **87** are raised, the T-shaped flanges **88** and **89** move downwardly until the pins **94** strike the upper surfaces of the slots **93.** This downward movement is sufficient to lower the pipe contacting surfaces of rollers **91** and **92** below the bottom of the supporting plate **33** of the stiffback. Thus, the pipe is allowed to rest within the stiffback.

Another set of conically shaped rollers **95** and **96** is carried by the main frame intermediate the inner end of the stiffback **32** and the pin-up shoe **57.** These rollers **95** and **96** project above the bottom of the supporting plate **33** of the stiffback and the bottom of the concave supporting surface of the pin-up shoe **57** at their lowered positions so the pipe can be easily brought into and rolled through the main frame.

Attached between side frames **21** and **22** above the die support **28** is a metallic plate **98** which supports a power winch **99** and other additional peripheral machinery. A cable leading from the drum of power winch **99** is utilized to pull the pipe through the main frame as will hereinafter be explained.

Mounted to side frame **21** is an internal combustion engine **100** for powering the various components of the pipe bending machine, including a pressure source (not shown) for the various cylinder and piston assemblies. The operation of the pipe bending machine and its various components, as well as the internal support elements to be hereinafter described, are controlled at the operator's station **101** through a group of hand lever actuated valves.

The conduits and valves for supplying hydraulic fluid under pressure to the inboard and outboard stiffback cylinder and piston assemblies, the stiffback clamp, the pin-up clamp, and the pin-up shoe are not shown in FIGS. **1, 2** or **3** and are not described herein in detail. It is believed that the manner of providing such hydraulic fluid to the various components of the bending machine is within the province of those skilled in the mechanical arts. For guidance, the artisan is referred to the hydraulic systems described in Coody U.S. Pat. No. 2,740,453 and Cummings U.S. Pat. No. 3,335,588. It is believed important, however, to point out particularly the manner of providing hydraulic fluid to the inboard and outboard stiffback cylinder and piston assemblies in the preferred embodiment of this invention. As illustrated in FIG. **21,** hydraulic fluid is supplied through conduit **102** to the stiffback control valve **103.** The flow from control valve **103** is directed through a sequence valve **104** which functions to insure that a preselected magnitude of hydraulic pressure is supplied through conduit **105** to the inboard stiffback cylinder and piston assemblies **37, 38, 39** and **40** before sufficient hydraulic pressure is supplied through conduit **106** to the outbaord stiffback cylinder and piston assemblies **44, 45, 46** and **47** to impart bend to the pipe. The sequence valve used may be any of numerous commercially available devices such as a Vickers RC CT-**10.** A relief valve **107** is attached to the system for rapidly dumping the hydraulic fluid should the need arise. This system of supplying hydraulic fluid to the stiffback cylinder and piston assemblies allows the operator properly to apply bend to the pipe as will hereinafter be explained.

In order to impart a proper cold bend to large diameter, thin-wall pipe, wherein the bent pipe is circular in transverse section and is not wrinkled or crimped, it is necessary to provide internal support for the pipe during the bending process. The improved pipe bending system according to this invention includes an internal stiffback support **110,** an internal pin-up support **111,** and an internal pipe supporting mandrel **112.** Referring to FIGS. **1, 2** and **3,** the internal stiffback support **110** and pin-up support (not shown) function to prevent the pipe from buckling, wrinkling or crimping inwardly at points spaced from the bending die **30.** The mandrel **112** functions to prevent the pipe from buckling, wrinkling or crimping inwardly adjacent the bending die **30.** The internal stiffback support **110** and pin-up support **111** preferably are aligned and utilized with the stiffback clamp **72** and the pin-up clamp **66,** respectively. The mandrel **112** is, of course, utilized with the bending die **30.**

It has been determined that the internal stiffback support **110** and pin-up support **111** need not be used conjunctively with the stiffback clamp **72** and pin-up clamp **66** with every bend of the pipe. Each is needed only when an end of the pipe is adjacent or in the respective stiffback clamp **72** or pin-up clamp **66.** For example, in FIG. **3,** neither end of the pipe **73** is adjacent the stiffback clamp **72** or the pin-up clamp **66** and thus neither the internal stiffback support **110** nor the internal pin-up clamp **111** is needed. Due to this selective need for the internal stiffback support and the pin-up support, in the preferred embodiment of this improved pipe bending system each is mounted on the pipe bending machine **20** rather than on the mandrel **112.** Preferably there is a pair of flanges **113** secured to side frame **21** adjacent the pin-up end of the machine and to the outer stiffback support assembly **48.** Rotatably journaled in each pair of the flanges **113** is a vertical beam **114.** Secured to each of the beams **114** and extending outwardly therefrom is a horizontal davit **115** carrying a horizontally movable trolley assembly **116** (the pin-up trolley assembly is not shown). Depending from each of the trolley assemblies **116** through a universal joint assembly **117** and **118** and a flexible expansible cylinder and piston assembly **119** is the respective internal stiffback support **110** or internal pin-up support. Each of the internal stiffback support **110** and the internal pin-up support **111** is inserted into the end of the pipe manually by swinging the davit **115** in to position and adjusting the height and location of the support until it will enter the pipe. Although the internal stiffback support **110** and pin-up support **111** are preferably mounted on the pipe bending machine, either or both of them alternatively may be attached to the ends of the internal support mandrel **112** so that when the mandrel **112** is properly positioned with respect to the bending die **30** each of the supports **110** and **111** is properly positioned with respect to the stiffback clamp **72** and pin-up clamp **66,** respectively.

The preferred construction of the internal stiffback support **110** and pin-up support **111** will be described after the mandrel **112** is described.

The improved internal pipe supporting mandrel **112** according to this invention is schematically illustrated collapsed within the pipe **73** in side elevation view in FIG. **15.** The mandrel **112** preferably comprises an upper assembly **120** and a lower assembly **121** mechanically linked together as will hereinafter be explained to provide an elongated, expansible, longitudinally flexible apparatus for providing the required support to the interior of the pipe adjacent the pipe bending die **30** during bending. Attached to the two ends of the upper assembly 120 in a manner to be herinafter explained are end plates 122 and 123. Secured to each of the end plates 122 and 123 is a downwardly extending wheel support assembly including a plurality of supporting arms 124. Rotatably attached to each of the wheel support assemblies are at least two wheels 125 for allowing the mandrel 112 to move along the stiffback 32 and into, along and out of the pipe 73. The construction of the wheel support assemblies and the attachment of the wheels thereto may be similar to that described in Avera et al, U.S. Pat. No. 3,109,477 provided, of course, that the wheels and wheel support assemblies depend only from the upper assembly 120 of the mandrel. Power means are secured to the wheels and within the wheel support assembly on one end of the mandrel to provide rotational force to the wheels and thereby move the mandrel. This power means may be a diesel engine, a fluid motor as described in Avera et al, U.S. Pat. No. 3,109,477, or any commercially available device well-known to those skilled in the art. In the preferred mandrel according to this invention, the lengths of the supporting arms 124 comprising the wheel support assemblies are chosen such that the wheels 125 are in contact with the curved supporting surface, whether it be the stiffback 32 or the pipe 73, only when the mandrel 112 is collapsed. On the other hand, when the mandrel 112 is expanded as will hereinafter be explained, the upper assembly 120 moves upwardly and thereby moves the wheels 125 upwardly out of contact with the supporting surface. Alternatively, the wheels 125 may be attached to pivotal members which can selectively move the wheels radially into and out of contact with the supporting surfaces as taught in Avera et al, U.S. Pat. No. 3,109,477.

The preferred construction of the upper and lower assemblies 120 and 121 and the interconnecting mechanical linkages is illustrated in FIGS. 16 through 19. The upper assembly 120 comprises an elongated, transversely plano-convex support apparatus which provides a longitudinally flexible transversely convex foundation for a plurality of hydraulic packers enveloped in a resilient material. The lower assembly 121 comprises an elongated, transversely plano-convex support apparatus which provides a longitudinally flexible, transversely convex foundation for means for engaging the lower portion of the pipe. Connecting the upper and lower assemblies 120 and 121 is a mechanical assembly which functions to move the upper and lower assemblies away from (referred to as expanding the mandrel) and toward (referred to as contracting or collapsing the mandrel) each other. Unlike many of the prior art mandrels, the improved mandrel according to this invention does not have a perfectly circular transverse shape when collapsed and does not expand radially to maintain a circular shape. Rather, its transverse shape when collapsed is that of two adjacent plano-convex segments, the convex circular surface of each being less than a semicircle. When the mandrel is expanded, the two plano-convex segments are moved away from each other and into engagement with opposite portions of the interior of the pipe, thereby providing a substantially circular support.

The mandrel is utilized with the apexes of the upper and lower assemblies substantially aligned with the plane passing through the apex of the pipe in the direction of the bend being imparted to the pipe. The upper assembly 120 is in contact with the portion of the pipe

associated with the bending die — the portion of the pipe which is compressed by the bend. The lower assembly 121 is in contact with the portion of the pipe associated with the stiffback — the portion of the pipe which is expanded or stretched by the bend. There is no internal support provided by the mandrel for the pipe between the upper and lower assemblies because the pipe in that area does not tend to buckle, wrinkle or crimp inwardly during bending.

The elongated, transversely plano-convex support apparatus of the upper assembly 120 preferably comprises first and second, elongated, planar, rectangularly-shaped spring steel members 125 and 126 laterally spaced apart from each other and extending the length of the upper assembly. Secured by welding or otherwise to the ends of the spring steel members 125 and 126 are the stout, transversely, plano-convex end plates 122 and 123. Secured to the two spring steel members 125 and 126 between the end plates 122 and 123 are seven identical convex foundation segments. Each of the seven segments preferably comprises a curved sheet 127 of spring steel arcing laterally between the two elongated spring steel members 125 and 126 with one end of the curved sheet 127 welded or otherwise secured to each of the members 125 and 126. The exterior of each of the curved sheets 127 of spring steel transversely forms a segment of a semicircle and functions as a part of the foundation for the hydraulic packers and the enveloping resilient material. Each curved sheet 127 of spring steel arcs between points spaced from the side edges of the two spring steel members 125 and 126 so that a portion of the elongated spring steel members 125 and 126 protrudes beyond the seven curved sheets 127 of spring steel and functions as a part of the foundation for the hydraulic packers and the enveloping resilient material. Each of the seven curved sheets 127 has a plano-convex rib 128 welded or otherwise attached to the inside thereof and between the two spring steel members 125 and 126. A plurality of circular, steel supporting rods 129 extend through the end plates 122 and 123 and through each of the seven curved sheets 127 of the upper assemblies. The rods 129 are attached to the end plates by welding or otherwise but slip through holes in the ribs 128 of the seven curved segments so that the foundation segments are free to move longitudinally thereon. A plurality of elongated back-up steel spring strips 130 are laid longitudinally along the exterior of the seven curved sheets 127 between the end plates 122 and 123. These elongated back-up strips 130 are not connected to the curved sheets 127. In securing the curved sheets 127 to the elongated members 125 and 126 between the end plates 122 and 123, a small space 131 preferably is left between adjoining segments. This allows the curved foundation segments to contract toward each other and thus insures longitudinal flexibility of the upper assembly 120. Arranged along the exterior of the elongated back-up strips 130 between the end plates 122 and 123 is a compressible, resilient material, such as polyurethane solid elastomer in the durometer range of 85 to 95. Preferably the resilient material is attached to the upper assembly in the form of seven curved segments 132, each of which is the same length as a corresponding curved sheet 127 and which is a truncated circular sector in transverse section. Each of the segments 132 of resilient material has preselected cavities cored out along its longitudinal length to receive certain elements which will be hereinafter described.

Secured to the two end plates (not shown in FIG. 17) and extending along the length of the upper assembly are a plurality of triangular filler springs **133.** Each filler spring **133** is adjacent to and overlaps two of the elongated back-up strips **130.** Each of filler springs **133** fits between two of the elongated segments **132** of resilient material in triangular spaces cored therein. Also secured to the end plates (not shown in FIG. 17) and extending longitudinally along the length of the upper assembly are a plurality of elongated, circular spring steel tie-bars **134.** Each tie-bar **134** is secured between two of the segments **132** of the resilient material in elongated, transverse semi-circular grooves cored in the sides thereof.

Extending through a relatively large, longitudinal, circular cavity in each segment **132** of the resilient material is an elongated inflatable bag **135,** such as a Lynes hydraulic packer. Each of the packers **135** extends through and slightly beyond the two end plates **122** and **123.** The ends of the hydraulic packers **135** preferably are hydraulically interconnected to each other (not shown) and to attendant hydraulic equipment (not shown) carried in the wheel support assemblies in the manner schematically illustrated in FIG. **20,** which will be hereinafter described.

Extending from the end plates **122** and **123** along the length of the upper assembly are a plurality of relatively flat, spring steel surface integrating strips **136.** Each surface integrating strip **136** fits within longitudinal receiving grooves cored in the exterior surface of the seven segments **132** of the resilient material so that the exterior surfaces of the strips **136** are flush with the exterior surfaces of the segments **132.** As illustrated in FIG. **17,** each end plate (only end plate **122** being shown) has an inwardly facing flange **137** along its convex surface. The segment **132** of resilient material adjacent each end plate has a shoulder cored out of its convex exterior surface to receive the flange. Receiving grooves are cut in the convex surface of the end plates to align with the receiving grooves cut in the exterior surfaces of the segments **132**; the surface strips **137** extend over the end plates **122** and **123** and are bolted thereto.

Secured across and connecting the undersides of the two elongated spring steel members **125** and **126** are seven transverse upper jaw members **140.** Each of the upper jaw members **140** has horizontal flanges **141** extending outwardly therefrom so the upper jaw member **140** can be bolted to the elongated members **125** and **126** vertically below a supporting rib **128.** Each of the upper jaw members **140** includes a plurality of downwardly facing cam surfaces **142** and shoulder **143.**

The elongated, transversely plano-convex support apparatus of the lower assembly **121** preferably comprises seven transverse planar lower jaw members **144.** Each transverse lower jaw member **144** is constructed to have a downwardly facing convex surface and a plurality of upwardly facing cam surfaces **142** and shoulders **143** corresponding to the cams and shoulders of the upper jaw members **140.** To decrease the weight of the lower jaw members **144,** each of them preferably contains a large internal cavity **145** with a plano-convex rib **146** welded therein. Secured to the downwardly facing convex surfaces of the seven lower jaw members **144** and extending longitudinally along the length of the lower assembly are a plurality of pairs of spring steel strips **147.** Attached to the exterior surfaces of the spring steel strips **147** throughout the lower assembly are a plurality of pipe engaging resiliently compressible blocks **148,** each of which preferably is constructed of the previously described polyurethane. The blocks **148** are bolted (not shown) to the strips **147** and, as illustrated in FIG. **16,** when a block is aligned with a lower jaw member **144,** both the block **148** and the strips **147** are bolted to the lower jaw member.

Each of the seven lower jaw members **144** is positioned vertically below an upper jaw member **140.** Positioned between each pair of upper and lower jaw members **140** and **144** are a pair of vertically disposed toggle bars **149.** Each toggle bar **149** has a plurality of protruding bosses **150** which communicate with the cam surfaces **142** and shoulders **143** of the upper and lower jaw members **140** and **144.** Each of the toggle bars **149** is linked for transverse movement to both the upper and lower jaw members through a plurality of mechanical linkages **151.** The mechanical linkages **151** are designed only to guide the transverse movement of the toggle bars **149.** They are not designed to transfer vertical forces. Vertical forces are transferred to the upper and lower assemblies **120** and **121** by the bosses **150** of the toggle bars moving transversely against the cam surfaces **142.**

FIG. **17** illustrates the mandrel in its collapsed position. Both of the toggle bars **149** are positioned in their most inward transverse position. The bosses **150** are resting in the cavities between the shoulders **143** of the upper and lower jaw members **140** and **144.** As force is applied to the toggle bars **149** to move them transversely outwardly away from each other, the bosses **150** move into contact with the cam surfaces **142** and, as illustrated in FIG. **19,** thereby force apart the upper and lower jaw members **140** and **144.** When the toggle bars **149** have moved to their extreme outward position, the mandrel is expanded. When the mandrel is expanded, the bosses **150** on the toggle bars **149** are in alignment and engagement with the shoulders **143** on the upper and lower jaw members **140** and **144** — and thus provide direct mechanical support locking the mandrel in its expanded condition.

The preferred apparatus for moving each of the toggle bars **142** in a pair thereof alternatively away from and toward each other is a plurality of cylinder and piston assemblies **152.** Preferably six toggle bar cylinder and piston assemblies **152** are utilized in parallel, each of which is positioned in the space existing between adjacent pairs of the toggle bars. As illustrated schematically in FIG. **15** and in detail in FIG. **18,** the toggle bar cylinder and piston assemblies **152** are connected in pairs to opposing drive flanges **153.** Each of the drive flanges **153** extends through and is secured to one toggle bar **149.** Each drive flange **153** has welded thereto an elongated hollow sleeve **154** which also is secured to and passes through the same toggle bar as the drive flange. Extending through the three aligned sleeves **154** and the seven aligned toggle bars **149** on each side of the mandrel is a continuous, circular drive bar **155** having an outside diameter less than the inside diameter of the sleeves **154.** Thus, expansion and contraction of the six toggle bar cylinder and piston assemblies **152** causes the pairs of drive bars **153,** sleeves **154** and toggle bars **149** attached thereto to move away from or toward each other. Movement of the pairs of sleeves produces movement of the two drive bars **155**, which in turn produces transverse movement of the remaining toggle bars **149**. Since the sleeves **154** are larger than the drive bars **155**, the drive bars may freely bend with the longitudinal flexing of the mandrel.

FIG. **19** illustrates an optional apparatus which may be attached to the linkage mechanism to insure that each toggle bar **149** in a pair moves transversely outwardly an equal distance. Secured to each of the innermost mechanical linkages (not shown) is a square drive pin **156**. A sprocket wheel **157** having teeth around its circumference is secured to each drive pin. Chains **158** are linked around opposing sprocket wheels in opposite directions whereby outward movement of one toggle bar causes rotation of the sprocket wheels attached to its pivoted linkages and equal but opposite rotation of the sprocket wheels attached to the pivoted linkages of the opposing toggle bar — thereby producing an equal outward movement of the opposing toggle bar.

In the preferred embodiment of the internal support mandrel according to this invention, there are 11 elongated hydraulic packers **135** enveloped in the polyurethane around the convex supporting surface of the upper assembly **120**. These packers are hydraulically interconnected so that varying pressures may be maintained in separate sets of the individual packers. This use of a plurality of distinct elongated hydraulic packers operated in sets is very advantageous and allows more accurate support and control of the pipe during the bending process. In the preferred embodiment of the internal support mandrel, the eleven individual packers are hydraulically interconnected as illustrated in FIG. **20**. The five packers **135***a* positioned from the apex of the upper assembly to approximately 25 °to 40 ° either side thereof are hydraulically connected in parallel. The remaining six packers **135***b*, the three on either side of the five center packers, are also hydraulically connected in parallel. Hydraulic fluid from tank **159** is pressurized by pump **160** and supplied through conduit **161** to valves **162** and **163** controlling the input to the five center packers **135***a* and the six outlying packers **135***b*, respectively. Valves **164** and **165** control the flow of the hydraulic fluid through conduit **166** back to the tank. Be selectively opening and closing the valves **162, 163, 164** and **165**, varying pressures can be maintained on the two sets of packers. For example, valves **164** and **165** can be closed and the input valves **162** and **163** opened. When the pressure in all of the packers has risen to a preselected magnitude such as 600 psi, valve **163** may be closed. The pressure will continue to build in the five center packers to a selected higher magnitude, such as 800 psi, until valve **162** is closed. By so selectively maintaining the pressure of the center packers higher than the pressure of the outlying packers, the pipe to be bent can be preshaped to "egg" out slightly vertically. Then when the bending forces are applied to the pipe and the pipe tends to "egg" out slightly laterally, a more circular shape will be produced in the bent pipe than is accomplished by prior bending systems.

The construction of the internal stiffback support **110** and the internal pin-up support **111** preferably is similar to the construction of the internal support mandrel **112**. Each of the internal supports **110** and **111** comprises a single segment of the internal support mandrel **112**. The first and second elongated spring steel members **125** and **126** described with respect to FIG. **17** are shortened to coincide with the length of a single curved sheet **127** of spring steel and two adjacent end plates. The lengths of the elongated hydraulic packers are of course also decreased. There is preferably only one set of toggle bars, which are pivotally attached to an upper jaw member secured to the upper assembly vertically beneath the supporting rib **128**. There is preferably only one lower jaw member **144** utilized. Secured to the sole lower jaw member around its convex lower surface are shortened strips of spring steel and pipe-engaging blocks. Preferably two toggle bar cylinder and piston assemblies are utilized, one on each side of the pair of toggle bars. The movement of the cylinder and piston assemblies **152** is transmitted to the toggle bars through drive flanges **153** attached to the toggle bar. The hydraulic fluid preferably is conducted to the cylinder and piston assemblies through flexible hoses (not shown) extending from the supports **110** and **111** to tanks and pumps (not shown) attached to the main frame of the pipe bending machine.

Additional advantages of this improved pipe bending system will become apparent in the following description of the preferred method of operation. FIG. **9** illustrates the pipe bending system in place to bend pipe. The internal support mandrel **112** is resting in its storage position in the outboard end of the stiffback **32**. A length of pipe **73** is brought into the pipe bending machine **20** from the pin-up end thereof. The length of pipe **73** is generally handled by a tractor and crane assembly **167** or the like. The pipe **73** is moved into and longitudinally along within the pipe bending machine **20** to a position where its forward end is adjacent the mandrel **112**. The mandrel **112** is then activated and moved into the pipe **73**. The pipe is then moved further along within the pipe bending machine **20** to the preselected position for imparting the first bend thereto. The mandrel **112**, which of course moved with the pipe **73**, is again activated and moved to its correct position with respect to the bending die **30** to support the pipe during the bend. The mandrel **112** can be properly located in the pipe with a "reach rod" attached to controls on the mandrel or by the use of an automatic positioning apparatus such as is described in the copending application of Edward A. Clavin, Donald H. McCullough and David R. McCullough, Ser. No. 129,702, filed Mar. 31, 1971 now U.S. Pat. No. 3,705,506. FIG. **10** illustrates schematically the pipe **73** moved into the pipe bending machine in the position for the first bend and the collapsed mandrel **112** positioned within the pipe. It should be noted that the pipe preferably is moved completely through the pipe bending machine so that the first bend is applied to the rear end of the pipe.

As illustrated in FIG. **11**, since the rear end of the pipe **73** is in close proximity to the bending die **30** and nearly aligned with the pin-up shoe **57** and pin-up clamp **66**, the internal pin-up support **111** is inserted therein. The operator then causes the pin-up support **111** to expand and the stiffback clamp **72** to close. The operator also transmits signals to the mandrel **112** to cause it to operate. The signals to the mandrel preferably are transmitted by the reach rod or by electrical lines connecting the mandrel to the operator's control station. There are two preferred methods of operating the improved internal support mandrel **112**. The hydraulic packers may be pressurized first and the upper and lower assemblies then moved into contact with the pipe. Or the upper and lower assemblies may first be moved into contact with the pipe and the hydraulic packers then pressurized. Utilizing the former method with the hydraulic packers maintained at constant pressures throughout the various bends is often advantageous because it allows the mandrel to be expanded and contracted very rapidly.

As illustrated in FIG. **12,** the operator then causes the hydraulic fluid pressure to the outboard and inboard stiffback cylinder and piston assemblies to be increased such that the stiffback is raised sufficiently to bring the pipe **73** into contact with the bending die **30.** Likewise, the pin-up cylinder and piston assembly is pressurized whereby the wedges **64** move the pin-up shoe upwardly into firm contact with the rearward end of the pipe. The pin-up clamp **66** is then closed.

At this point in the bending process the previously described sequence valve in the hydraulic system of the inboard and outboard stiffback cylinder and piston assemblies is utilized. The hydraulic pressure in the inboard stiffback cylinder and piston assemblies is increased to a selected magnitude, such as, 1,200 psi, before any additional pressure is supplied to the outboard stiffback cylinder and piston assemblies. This insures that once the outboard stiffback cylinder and piston assemblies start moving the outboard stiffback shaft **52** upwardly, sufficient vertical forces will have already been applied to the two inboard stiffback shafts **35** that they will conjunctively function as a pivot for the stiffback **32.**

FIG. **13** illustrates the improved pipe bending system according to this invention applying bend to the pipe. The stiffback **32** is tilted upward about the pivot point formed by the inboard stiffback shafts **35.** The pin-up shoe **57** functions as the fulcrum or support for the rear end of the pipe. The pin-up shoe **57,** the pin-up clamp **66** and the internal pin-up support **111** prevent the rear end of the pipe from becoming out-of-round. The stiffback clamp **72** and the stiffback **32** prevent the forward end of the pipe from becoming out-of-round. And the mandrel **112** prevents the pipe from buckling, wrinkling or crimping inwardly in the vicinity of the bend. The improved mandrel **112** according to this invention is positioned with respect to the bending die **30** so that a portion of the upper assembly of the mandrel extends beyond the stiffback or forward end of the die. This is because the bending of the pipe occurs on a relatively small section of the bending die **30** near its forward end. Also, as illustrated in exaggerated form in FIG. **22,** large diameter, thin-wall pipe **73** tends to buckle outwardly immediately adjacent the forward end of the die **30** and ripple or buckle **169** inwardly just beyond the outward bulge **168** as a result of the bending process. Thus, as illustrated in FIG. **23,** the mandrel **112** is positioned so that its upper assembly extends beyond the forward end of the bending die **30** sufficiently to support the pipe in the area of these bulges. Prior art internal pipe supporting mandrels, even if positioned properly with respect to the die, do not prevent these bulges. The improved mandrel **112** according to this invention prevents the inward bulge **169** and thus diminishes the outward bulge **168** and completely prevents the pipe from buckling, wrinkling or crinkling inwardly between the die and the stiffback in the region of the bend. The improved mandrel according to this invention accomplishes this superior support of the pipe for several reasons. First, the use of the plurality of individual mechanical apparatus for moving the upper and lower assemblies apart and locking them apart insures that, while the mandrel is longitudinally flexible, the downward forces on the convex foundation support of the upper assembly are rigidly transferred to the lower assembly. Second, the use of a plurality of distinct elongated hydraulic packers on the upper assembly insures that downward forces applied to one segment of the mandrel are integrated through other segments of the mandrel. For example, assume that each of the five center packers are pressurized to **800** psi. As the pipe is bent upwardly against the die, the pressure of the interior of the pipe wall against the urethane envelope may increase the pressure of the apex packer at one point along its length to 1,200 psi. Other adjacent packers may be increased a lesser amount. These increased pressures are communicated throughout the length of the elongated interconnected packers and function to increase the support of the pipe. The integrating nature of the pressures in the packers causes the mandrel to support the pipe firmly along the entire length of the mandrel and thus prevent any inward bulging. All the while the mandrel remains longitudinally flexible. Third, the use of a plurality of distinct elongated hydraulic packers on the upper assembly hydraulically interconnected in sets facilitates better control of the shape of the pipe. Indeed, pipe which may be irregularly shaped prior to the bend will be circular after the bend.

FIG. **14** illustrates the pipe **73** after the first bend has been imparted thereto and it has been moved to the position for the next bend. After the first bend, the mandrel **112** is collapsed and the pin-up clamp **66** opened. The pin-up shoe **57** and the stiffback **32** are then lowered. The stiffback clamp **72** is then released and the internal pin-up support **111** removed from the end of the pipe. A cable from winch **99** is hooked to the forward end of the pipe **73** and the pipe moved longitudinally toward the pin-up end of the machine for the next bend. The mandrel is then re-positioned. The entire bending process, excluding the use of the internal pin-up support **111,** described with respect to FIGS. **10** through **14** is then repeated as many times as necessary. When the forward end of the pipe approaches the stiffback clamp **72,** internal stiffback support **110** is utilized. The conjunctive use of the stiffback clamp **72** and the internal stiffback support **110** allow the pipe to be bent accurately and properly much closer to the forward end of the pipe than allowed by prior art systems. Likewise, the conjunctive use of the pin-up clamp and the internal pin-up support allow improved bending much closer to the rearward end of the pipe.

Thus, this invention provides an improved pipe bending system including an improved pipe bending machine and an improved internal pipe supporting mandrel. Many variations in the form of the preferred embodiment will now be apparent to those skilled in the art. For instance, the internal stiffback and pin-up support may depend from the mandrel. Additionally, many structural and hydraulic changes may be made in the various components of the system without departing from the invention. Therefore, the invention should not be limited to the preferred embodiment, but rather should extend to the full scope and spirit of the invention defined in the appended claims.

What is claimed is:

1. An improved pipe bending system, comprising:

a main frame having a pin-up end and a stiffback end;

a longitudinally convex and transversely concave elongated bending die for pipe bend confirmation thereto secured to the main frame intermediate its length, the face of the die being positioned downwardly so the pipe may be bent thereagainst;

a transversely concave elongated stiffback for bending the pipe against the die, the stiffback being movably secured by expansible and contractible means to the main frame and extending at least from a point adjacent the end of the die nearest the pin-up end of the main frame to a point adjacent the stiffback end of the main frame;

a movable expansible and contractible, internal pipe-supporting mandrel for supporting preselected portions of the internal wall of the pipe during bending;

means for positioning the mandrel within the pipe to be bent at preselected positions with respect to the die;

a transversely concave pin-up shoe for supporting the pipe movably secured to the main frame adjacent its pin-up end;

a pin-up clamp secured to the pin-up shoe for supporting a portion of the exterior wall of the pipe during bending; and

a stiffback clamp secured to the stiffback a preselected distance from the end of the die nearest the stiffback end of the main frame for supporting a portion of the exterior wall of the pipe during bending.

2. An improved pipe bending system according to claim **1,** including an expansible and contractible internal pin-up support associated with the pin-up end of the main frame for providing support for a preselected portion of the internal wall of the pipe during bending.

3. An improved pipe bending system according to claim **1,** including an expansible and contractible internal stiffback support associated with the stiffback end of the main frame for providing support for a preselected portion of the internal wall of the pipe during bending.

4. An improved pipe bending system according to claim **2,** where the internal stiffback support comprises:

an upper assembly presenting a transversely convex pipe engaging surface, at least a portion of which is a resiliently compressible material;

a lower assembly presenting a transversely convex pipe engaging surface; and

means for selectively moving the upper and lower assemblies away from each other and into engagement with the interior of the pipe.

5. An improved pipe bending system according to claim **1,** wherein the means for movably securing the stiffback to the main frame includes:

at least two inboard cylinder and piston assemblies connected to the stiffback and the main frame intermediate its length for providing a pivot for the stiffback during the bending process; and

at least two outboard cylinder and piston assemblies connected to the stiffback and the main frame adjacent the stiffback end thereof for providing the bending forces required by the stiffback to bend the pipe against the die.

6. An improved pipe bending system according to claim **5,** wherein the outboard and inboard cylinder and piston assemblies are hydraulically operating and including:

means on the main frame for supplying hydraulic fluid under pressure to the assemblies; and

a sequence valve connected to the means for supplying hydraulic fluid for regulating the supply and the pressure of the hydraulic fluid so that the pressure of the fluid supplied to the inboard assemblies is of a preselected magnitude before the pressure of the fluid supplied to the outboard assemblies is increased sufficiently for the stiffback to bend the pipe against the die.

7. An improved pipe bending system according to claim **1,** wherein the stiffback clamp includes:

a first arcuate supporting plate hinged to the top of the one side of the stiffback;

a second arcuate supporting plate hinged to the top of the other side of the stiffback;

a third arcuate plate connected to the first plate and slidable around the outer surface of the second plate;

a locking toggle mechanism connected between the second plate and the third plate; and

a cylinder and piston assembly connected between the locking toggle mechanism and the second plate for operating the locking toggle mechanism.

8. An improved pipe bending system according to claim **1,** wherein the internal support mandrel includes:

an elongated, longitudinally flexible upper assembly for providing support to the interior wall of the section of the pipe in contact with the bending die, the upper assembly including at least one hydraulic packer mounted in a resiliently compressible pipe engaging material;

an elongated, longitudinal flexible lower assembly for providing support to the interior wall of the section of the pipe in contact with the stiffback in the vicinity of the die; and

means secured to and between the upper and lower assemblies for selectively moving the assemblies away from and toward each other and into and out of engagement with the interior wall of the pipe.

9. An improved pipe bending system according to claim **8** wherein the upper assembly includes:

a plurality of elongated hydraulically inflatable bags hydraulically connected in sets; and

a resiliently compressible material enveloping the bags and presenting a transversely convex pipe engaging surface.

10. An improved pipe bending system according to claim **9** wherein the upper and lower assemblies and the means for moving the upper and lower assemblies apart from each other include:

downwardly facing cam surfaces and shoulders mounted on the upper assembly;

upwardly facing cam surfaces and shoulders mounted on the lower assembly;

at least one transversely movable toggle bar having bosses protruding therefrom for contacting the cam surfaces and shoulders and mounted between the upper and lower assemblies; and

at least one cylinder and piston assembly mounted between the upper and lower assemblies for transversely moving the toggle bar;

the shoulders on the upper and lower assemblies and the toggle bar forming a sturdy mechanical support between the upper and lower assemblies when the mandrel is in its expanded condition.

11. An improved pipe bending system according to claim **1,** including:

an expansible and contractible internal stiffback support associated with the mandrel so that when the mandrel is properly positioned with respect to the bending die, the stiffback support is positioned in a selected relationship with respect to the stiffback clamp; and

an expansible and contractible internal pin-up support associated with the mandrel so that when the mandrel is properly positioned with respect to the bending die, the pin-up support is positioned in a selected relationship with respect to the pin-up clamp.

12. An improved pipe bending machine, including:

a main frame having a stiffback end and a pin-up end;

a pipe bending die secured to the main frame intermediate its length;

a stiffback movably connected to the main frame through expansible and contractibel cylinder and piston assemblies for bending pipe against the die;

a pin-up shoe movably connected to the main frame adjacent its pin-up end;

a pin-up clamp secured to the pin-up shoe; and

a stiffback clamp secured to the stiffback.

13. An improved pipe bending machine according to claim **12,** including:

an internal pin-up support flexibly associated with the pipe bending machine adjacent to the pin-up clamp; and

an internal stiffback support flexibly associated with the pipe bending machine adjacent to the stiffback clamp.

14. An improved pipe bending machine according to claim **13,** wherein each of the pin-up support and the stiffback support comprises:

an upper assembly presenting a transversely convex pipe engaging surface, at least a portion of which is a resliently compressible material;

a lower assembly presenting a transversely convex pipe engaging surface; and

means for selectively moving the upper and lower assemblies away from each other and into engagement with the interior of the pipe.

15. An improved pipe bending machine according to claim **12,** wherein the expansible and contractible cylinder and piston assemblies movably connecting the stiffback to the main frame include:

at least one inboard hydraulic cylinder and piston assembly connected to each side of the stiffback and the main frame intermediate its length, the inboard cylinder and piston assemblies being positioned in a selected relationship to the bending die to provide a pivot for the stiffback during the bending process; and

at least one outboard hydraulic cylinder and piston assembly connected to each side of the stiffback and to the main frame adjacent its stiffback end, the outboard cylinder and piston assemblies providing the upward forces on the stiffback for bending the pipe held in the stiffback against the die; and

means for supplying hydraulic fluid under pressure to the inboard and outboard assemblies, including a sequence valve for allowing the pressure of the hydraulic fluid supplied to the inboard assemblies to exceed a preselected magnitude prior to the pressure of the hydraulic fluid supplied to the outboard assemblies increasing to a magnitude sufficient for the stiffback to bend the pipe against the die.

16. An improved pipe bending machine according to claim **12,** wherein the stiffback clamp includes:

means for providing support for a selected portion of the exterior wall of a pipe held in the stiffback pivotally secured to the stiffback adjacent the end of the die nearest to the stiffback end of the main frame and movable between open and closed positions; and

means secured to the support means for selectively moving the support means between the open and closed positions;

the support means and the stiffback conjunctively providing nearly full circular support for the pipe when the support means is moved to the closed position.

17. An improved pipe bending machine, including:

an elongated main frame for receiving the pipe to be bent, the main frame having a pin-up end and a stiffback end;

a downwardly facing die presenting a longitudinally convex and transversely concave surface against which the pipe is to be bent, the die being secured to the main frame intermediate its length and adjacent its highest elevation;

an upwardly facing stiffback presenting an elongated, transfersely concave surface for cradling the pipe to be bent and for bending the pipe against the die, the stiffback being movably connected to the main frame;

a pin-up shoe movably connected to the main frame adjacent its pin-up end for providing the fulcrum for the end of the pipe which is to remain stationary during the bending process, the pin-up shoe providing a transversely concave surface in which the pipe is cradled;

a pin-up clamp attached to the pin-up shoe; and

a stiffback clamp attached to the stiffback intermediate the stiffback end of the main frame and the end of the bending die nearest the stiffback end of the main frame, the stiffback clamp being expansible to allow the pipe to be moved longitudinally through the stiffback and being contractible to provide with the stiffback nearly full circular support for a selected portion of the exterior wall of the pipe during the bending process.

18. An improved pipe bending machine according to claim **17,** including an expansible and contractible pin-up support flexibly depending from a rotatable davit attached to the main frame adjacent its pin-up end for providing internal support to the rearward end of the pipe during the bending process whenever the rearward end of the pipe is adjacent the pin-up clamp.

19. An improved pipe bending machine according to claim **17,** including an expansible and contractible stiffback support flexibly depending from a rotatable davit attached to the means movably connecting the stiffback to the main frame for providing internal support to the forward end of the pipe during the bending process whenever the forward end of the pipe is adjacent the stiffback clamp.

20. An improved method of bending pipe, including the steps of:

cradling the portion of the pipe to be bent in a stiffback and beneath a bending die;

cradling the rearward portion of the pipe extending from the stiffback in a pin-up shoe;

positioning an internal support mandrel inside the pipe in a selected space relationship with the bending die;

inflating a plurality of individual, elongated, inflatable bags included in the mandrel to varying magnitudes of pressure with the greatest pressure in the bags adjacent the apex of the portion of the pipe to be bent against the die;

performing in any sequence the steps of:

closing a stiffback clamp secured to the stiffback around the pipe;

expanding the mandrel against the interior wall of the pipe thereby shaping the pipe so it is elongated slightly in the direction of the die;

applying upward forces to the stiffback adjacent the die and adjacent the forward end of the stiffback to raise the stiffback and the pipe cradled therein sufficiently for the pipe to lightly contact the die;

applying upward forces to the pin-up shoe to raise the pin-up shoe into firm supporting contact with the rearward portion of the pipe;

closing a pin-up clamp secured to the pin-up shoe around the pipe;

increasing the upward forces being applied to the stiffback adjacent the die to a selected magnitude; and

increasing the upward forces being applied to the stiffback adjacent its forward end to a selected magnitude whereby the forward end of the stiffback pivots upwardly, thereby bending the pipe against the die with the rearward portion of the pipe held stationary by the pin-up shoe.

21. An improved method of bending pipe according to claim **20,** including at some point prior to the step of increasing the upward forces on the forward end of the stiffback sufficient to pivot the stiffback, the steps of:

if the rearward end of the pipe is adjacent the pin-up clamp, expanding an internal pin-up support positioned in a selected space relationship with the pin-up clamp against the interior wall of the pipe; and

if the forward end of the pipe is adjacent the stiffback clamp, expanding an internal stiffback support positioned in a selected space relationship with the stiffback clamp against the interior wall of the pipe.

22. An improved method of bending pipe according to claim **20,** including at some point prior to the step of increasing the upward forces on the forward end of the stiffback sufficient to pivot the stiffback, the step of expanding an internal pin-up support and an internal stiffback support inside the pipe and providing support for portions of the interior wall of the pipe at locations spaced from the mandrel.

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