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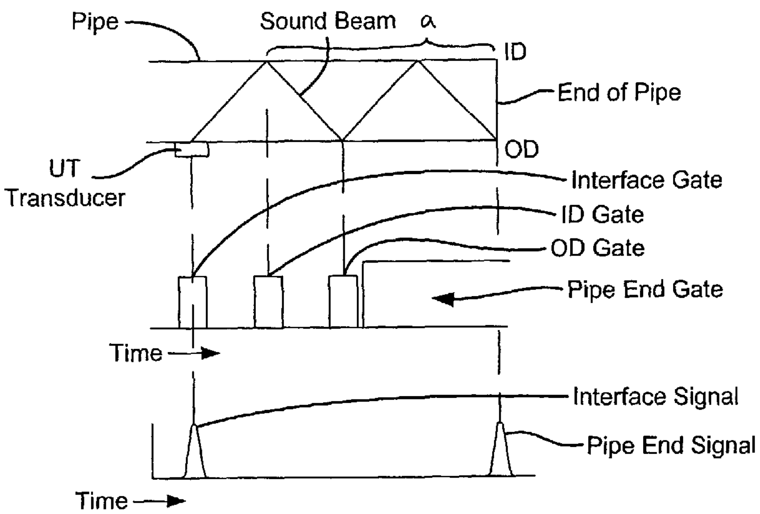
(54) Title: A METHOD AND APPARATUS FOR INSPECTING A PRODUCT WITH ULTRASOUND



(57) Abstract: A method of inspecting a product with ultrasound, which method comprises the steps of: (a) transmitting ultrasonic waves into the product with a transducer means such that they are internally reflected from a first surface, a second surface, and from an end of the product; (b) receiving ultrasonic waves reflected from the end of the product and from any defects in the first and second surfaces; (c) generating a position signal representative of the position of the transducer means with respect to said end; (d) using said position signal to enable inspection of substantially the entire first surface of the product, while continuing to inspect the second surface of the product; and (e) thereafter disregarding any indication of a defect in said first surface while using said position signal to enable inspection of substantially the entire second surface of the product.

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Method and Apparatus for Inspecting a Product with Ultrasound

The present invention relates to a method and apparatus for inspecting a product with ultrasound, to a product for use in the method and with the apparatus, and to a body for mounting a plurality of ultrasonic transducers.

Flaws and defects in tubular members can result in the failure of the tubulars. Replacement or repair of a defective tubular can be time-consuming and expensive. In the oil and gas industries, tubular members used in drilling and other oil field operations are constructed from metal alloy and are examined before use to detect and locate defects. Often a defect can be removed and the tubular used for its intended purpose. In other cases, the defect cannot be fixed and the tubular is rejected. Whether the tubular member can be used is based on characteristics of a defect, e.g. size, shape, location and orientation. In any event it is important that defects are identified before a tubular is used.

In some cases, defects located on a surface (interior or exterior) of a tubular can be visually characterized and examined to determine whether removal of the defect is necessary and possible - and whether removal is feasible by grinding or other means; but often such visual examination of a defect is not accurate or is not possible.

Certain prior art ultrasonic inspection devices have used ultrasonic beams to locate defects in tubular members. Ultrasound is defined as mechanical vibrations with frequencies beyond the upper limits of the human ear i.e. approximately 20kHz upwards. There is no theoretical upper limit to ultrasonic frequency, although ultrasonic applications are usually restricted to about 20MHz.

Typically ultrasonic transducers used in the inspection of products operate at frequencies of 2.25MHz, 3.5MHz, and 5MHz, although other frequencies are possible of course. In certain systems the apparatus employed uses a piezoelectric crystal or crystals, each of which produces ultrasonic vibrations in response to the application of a voltage. Such systems often use a method in which a crystal is held in a position relative to the pipe surface and is energised to transmit a short duration sonic wave pulse of beamed energy into the wall of the pipe, and is then de-energised to be in a "receive" mode. The ultrasound is emitted at an angle such that at a flaw or discontinuity in the pipe causes the waves to be reflected back and produce a voltage response in the crystal to produce a corresponding electrical signal which may be analyzed for determining the nature and location of flaws. For example, U.S. Patent No. 4,217,782 describes an ultrasonic inspection device for inspecting tubular members for the oil and gas drilling industries that employs two pairs of line-focused transducers that transmit sonic beams having a rectangular beam cross-section of about 3/4 inch in length. A first pair of the transducers transmits sonic beams longitudinally into the member to detect transverse defects. The second pair transmits sonic beams transversely into the member to detect longitudinal defects. The transducers in each pair transmit sonic beams in opposite directions. Two additional transducers monitor the wall thickness of the tubular member. Sonic beams transmitted longitudinally and transversely are used for the inspection of tubular members since defects are visible to only one or the other. Some flaws and defects are invisible to both longitudinally and transversely transmitted sonic beams. In certain prior art systems, the ultrasonic inspection device of U.S.

Patent No. 4,217,782 has been modified to include four spot-focused transducers that transmit sonic beams having a circular beam cross-section obliquely through a tubular member and a pair of transducers that transmit in opposite directions has been used to detect defects in tubular members as described in U.S. Patent No. 3,289,468 since a given defect may be invisible to a transducer looking at it from one direction and visible to a transducer looking at it from the opposite direction.

In order to characterize a defect for size, shape, and orientation sonic beams are, in certain prior art systems, transmitted from several different directions followed by the receiving of beams reflected from the defect. As described in U.S. Patent No. 3,332,278, reflected beams from one transducer have been received by several transducers to detect some of the defects.

U.S. Patent 4,718,277 discloses an ultrasonic inspection device having an array of opposing transducers that longitudinally, transversely, and obliquely transmit sonic beams through tubular members having a range of diameters such that refracted beams meet on the inner surface of the members. Alternate halves of the array of transducers transmit and receive sonic beams reflected from defects in the tubular members using both the pulse-echo and pitch-catch methods.

U.S. Patent 5,007,291 discloses ultrasonic inspection apparatus with centring means for tubular members that has pipe inspection apparatus with transducers for transmitting pulsed beams of ultrasonic energy longitudinally, transversely and obliquely into the wall of the pipe for detection of flaws. The apparatus includes a motor driven chuck for rotating the transducers about a pipe and a motor driven roller for axial movement of the pipe whereby the transducers move in a helical scanning path. A control system maintains the axes of the pipe and circle array of transducers in coincidence and with hydraulic controls maintains each transducer at fixed distance to the pipe for sonically coupling thereto by a flowing liquid whereby a shear wave is generated by each beam in the tubular wall. The transducers comprise multiple pairs, the members of which are diametrically opposed and transmit in opposite directions, for transmitting longitudinally at angles of 12 degrees, 27 degrees and 42 degrees to the pipe axis both clockwise and counter clockwise with one transducer of each pair disposed to transmit forward and the other reverse. For longitudinal flaws, one transducer of a pair transmits transverse clockwise and the other transverse counter clockwise. All transducers that transmit in a given direction are arrayed in the axial direction of the pipe. A first pair of pulsers simultaneously and repetitively energize and de-energize all forward transmitting transducers and after each such transmission a second set of pulsers simultaneously and repetitively energize and de-energize all reverse transducers. Reflection signals of predetermined strength are recorded and activate an alarm. A compressional wave transducer for determining wall thickness is included.

U.S. Patent 5,313,837 discloses an ultrasonic thickness gauge for pipe, which in certain aspects is a compact ultrasonic tester involving rotating sensors. A processor rotates with the sensors so that the output signal of the processor goes through slip rings, rather than to output signal of the sensors. A spraying system is incorporated in conjunction with rollers. The rollers take the applied spray on the pipe surface and paint a film on the outer pipe surface to allow a good contact for meaningful results. A floating shoe is provided for holding each sensor against the pipe wall. The sensors are biased into contact with the pipe surface and the machine can handle different diameters of pipe. By controlling the pipe speed of advance and the rotational speed of the sensors, a large percent coverage of the pipe wall is assured. The machine is compact and can be installed behind existing electromagnetic/gamma testers without major modifications to pipe-testing facilities.

U.S. Patent 5,585,565 discloses a method for the ultrasonic inspection of pipe and tubing and a transducer which has an elastic membrane used to form a reservoir of ultrasonic fluid coupled to ultrasonic transducers with the membrane conforming to the surface of the tubing being inspected. Guide wheels maintain the membrane out-of-contact with the tubing during relative rotational movement of the assembly and tubing during inspection. Water is introduced between the membrane and the tubing to provide ultrasonic coupling of the tubing to the transducers through the fluid of the reservoir. Each of the patents mentioned above is incorporated fully herein in its entirety for all purposes.

Known automated ultrasonic systems for detecting flaws and defects in tubulars have been unable to adequately, accurately, and correctly detect inner surface defects relatively near the ends of the tubular member. They can normally test up to 1.3 to 5 times the thickness of the pipe, e.g., within two feet or within eighteen inches of the ends up to the end boundary surface. For example, about eighteen to twenty four inches of the length of a thirty-foot casing, ten and three-fourths inches in diameter, is often not accurately examined by certain automated prior art systems. In particular, detection of defects oriented substantially along the axis of the pipe is relatively straightforward with sound emitted substantially perpendicularly to the axis of the pipe. However, where the defect is oriented substantially perpendicular to the axis, sound emitted in this fashion does not always generate a clear enough signal to highlight the defect. One solution has been to emit ultrasound into the pipe at an oblique angle to the axis of the pipe. In this way there is a greater chance that the sound will be reflected from such a defect with a detectable signal. However, when inspecting near the end of the pipe these sound waves are reflected from the end wall back to the transducer. It is not always easy to determine whether a received signal results from the end of the pipe or from a defect. Accordingly there is a portion near the end of the pipe, typically of the aforementioned magnitude, in which automated flaw detection has been uncertain at best and not possible at worst. To overcome this the ends of such tubulars are often examined manually with portable electromagnetic or ultrasonic testing equipment in a time-consuming process. It is to be noted that, whatever portion of the pipe is under inspection there will always be a signal generated by reflection from the pipe end. However, when a transducer is some distance from the pipe end, the pipe end signal is usually not received back at the transducer before inspection of that portion has been completed. Alternatively the pipe end signal is attenuated and lost in noise.

There has been a need for an automated ultrasonic inspection method and apparatus that is capable of automatically detecting and characterizing flaws and defects in tubular members (and other shaped goods, for example plate and sheet) and for such apparatus and methods that can do this for inner surface defects near or at the ends of the tubulars. There has long been a need for apparatus and methods for detecting defects in welds in, on, or between tubulars, e.g., but not limited to, the examination of girth welds of tool joints.

The present invention, in certain embodiments, discloses a method and apparatus for detecting defects in tubular members which is capable of examining substantially all of the length of a tubular; and, in certain aspects, which can accurately detect flaws including inner surface defects in substantially all of a tubular's length and near or at its ends. In certain aspects this is accomplished with a method and an apparatus that nullifies, cancels, or ignores information from a signal reflected from a tubular end (or signals) - i.e. other than a signal or signals related to inner surface defects - transmitted to and reflected from the tubular. In one embodiment the apparatus and method can inspect a tubular to within approximately 2 or 3mm of its ends.

In certain embodiments according to the present invention, signal information related to a signal reflected from the end of the tubular is used by an electronic processing means (for example a computer) to determine the distance from ultrasonic transducers to the end of the tubular toward which the transducers are moving, but not for outer surface (outer diameter or "O.D.") flaw detection; and, at the same time, the system sends and receives signals for the examination of the inner surface (inner diameter or "I.D.") of the tubular member relatively near its end. By knowing the distance from the ultrasonic transducer(s) to the end of the tubular member, once the tubular's outer surface has been examined, signals other than those related to examination of the inner surface and determining the distance to the tubular end can be ignored.

In certain aspects a method and an apparatus according to the present invention employs a transducer mount, body or "shoe" that has a plurality (two, three, four, five or more) of ultrasonic transducers each of which can emit a beam that is reflected back to a receiving ("listening") transducer. In one aspect the reflected beams pass through a single beam passage area of the shoe for receipt by one of the transducers that is not in a beam-emitting mode (a "listening" mode).

In one embodiment a shoe according to the present invention has a waveguide support for transducers that is made of Lucite (trademark) plastic or of similar plastic (or of low loss ultrasonic material). Multiple - e.g., two, three, four or five - transducers are mounted relatively close to each other. Each transducer is mounted at a prescribed angle so that, in certain aspects, all reflected beams pass through the single beam passage area of the waveguide and are directed back to one of the transducers. In certain aspects such a system may also have one, two or more transducers located apart from the plastic waveguide support for examining the wall thickness of the tubular being studied. Alternatively, the wall-thickness transducer(s) may also be supported by the plastic waveguide support. Optionally a wear member may be mounted adjacent the plastic waveguide support and between it and a tubular for contacting the outer surface of the tubular being examined. The wear member may be a plate with a curved surface corresponding in shape to the curved outer surface of the tubular; it may be a flexible member made of flexible rubber, plastic, or similar material; or it may be an inflatable member such as a bladder or balloon whose contents (e.g. water that acts as a waveguide) is adjusted to provide a shape that corresponds to the shape of the tubular. Fluid inlet(s) and outlet(s) in the shoe (e.g., but not limited to, in the plastic waveguide support or a mount in which the plastic waveguide support is held) provide fluid to the space between the wear member and the pipe being inspected so that there is no air in this space to impede transmission of the ultrasonic beams. Typical fluids for this include water, silicone, oil, and/or glycol. With a plastic waveguide the angle of refraction of the material is typically about 35.8 degrees. With systems in which the ultrasonic beams are transmitted through water, the angle of refraction is typically about 18.8°.

In certain apparatus and methods according to the present invention a weld on, in or between tubular members is inspected. In one particular embodiment a girth weld (e.g. welding a tool joint to another piece of pipe) is inspected for flaws. In one aspect such a system is automated so that a welded tool joint is rotated adjacent a transducer mount with one, two, three, four, five or more tranducers thereon. The transducer mount is moved axially along the length of the joint as it rotates radially so that the entire weld is inspected. Any suitable apparatus for moving the transducer mount adjacent the joint may be used. In one particular aspect the mount is moved continuously until it is adjacent a weld portion; then optionally the mount is moved so that in a position immediately past the weld and the mount is held stationary there while the joint continues to rotate radially adjacent the transducers - thus insuring that the entire weld is inspected and the weld thickness past the weld is examined. Alternatively, the transducer mount is moved along the entire joint length in pre-set incremental steps and the final step is of sufficient temporal duration that the joint continues to rotate through the final step duration so that the wall thickness of the entire weld is inspected. By purposefully moving an ultrasonic transducer apparatus very near or past a weld, the entire weld is subjected to a full ultrasonic beam width.

According to one aspect of the present invention there is provided a method of inspecting a product with ultrasound, which method comprises the steps of:

(a) transmitting ultrasonic waves into the product with a transducer means such that they are internally reflected from a first surface, a second surface, and from an end of the product;

(b) receiving ultrasonic waves reflected from the end of the product and from any defects in the first and second surfaces;

(c) generating a position signal representative of the position of the transducer means with respect to said end;

(d) using said position signal to enable inspection of substantially the entire first surface of the product, while continuing to inspect the second surface of the product; and

(e) thereafter disregarding any indication of a defect in said first surface while using said position signal to enable inspection of substantially the entire second surface of the product. In one embodiment all of the output signals are electrical and are processed by a computer processing means. It is preferred that the method is automated for speed of inspection. In one embodiment the position signal is obtained by processing a portion of an output signal from the transducer means representative of waves reflected from said end to obtain a distance from the transducer means to the end of the product. In another embodiment the position signal is generated by sensing means that generate a signal at a predetermined location of the transducer means with respect to the end. It has be found that transmitting ultrasound into the product at an angle of 30° to 45° to its surface has produced good results; 45° has been found most advantageous. In another embodiment the method is useful on products having a thickness of at least approximately 3.5mm. If the thickness is any less, the ultrasound has difficulty propagating in the product.

Preferred steps of the method are set out in claims 2 to 22 to which attention is hereby directed.

According to another aspect of the present invention there is provided an apparatus for inspecting a product with ultrasound, which apparatus comprises:

(a) transducer means for transmitting ultrasonic waves into the product such that they are internally reflected from a first surface, a second surface and an from end of the product;

(b) means for receiving ultrasonic waves reflected from the end of the product, and any defects in the first and second surfaces;

(c) generating means for generating a position signal representative of the position of the transducer means with respect to said end;

the arrangement being such that, in use, said position signal is used to enable inspection of substantially the entire first surface of the product, while continuing to inspect the second surface of the product, and thereafter any indication of a defect in said first surface is disregarded while using said position signal to enable inspection of substantially the entire second surface of the product.

Preferred features of the apparatus are set out in claims 24 to 41 to which attention is hereby directed.

Another problem with which the present invention is concerned is that, although defect detection advantages are obtained using multiple transducers, they each have to be coupled to the pipe individually. Furthermore, it is necessary for some sizes of pipe to couple the transducers to the top and for other sizes of pipe to couple them to the bottom of the pipe. This can result in wasted inspection time.

According to another aspect of the present invention there is provided a body for mounting a plurality of ultrasonic transducers, which body comprises a plurality of positions at which said plurality of transducers can be mounted respectively, and waveguide means that, in use, guide waves from each transducer through a single opening in the body to a product under inspection, and through which single opening waves reflected from the product pass and are guided back to the transducers by said waveguide means. This saves the time of coupling each transducer to the pipe in the correct position and permits all of the transducers to be moved in one unit. When the body is coupled in the new position all of the transducers will automatically be in the correct position with respect to the pipe.

* * *

According to another aspect of the present invention there is provided a method for ultrasonically inspecting a tubular member, the tubular member having an inner surface, an outer surface, and two spaced-apart ends including a first end of the tubular member, the method comprising

transmitting sonic beams to the tubular member with transducers such that sonic beams are reflected from: the inner surface of the tubular member, the outer surface of the tubular member, and from the first end of the tubular member,

completing inspection of the outer surface of the tubular member for outer surface defects while continuing to inspect the inner surface of the tubular member for inner surface defects,

while continuing to inspect the inner surface of the tubular member for inner surface defects, sensing a distance from the transducers to the first end of the tubular member, and, the transducers continuing to transmit sonic beams for the inspection of the inner surface of the tubular member until the transducers are near the first end of the tubular member. ignore

Preferably, the tubular member has an inner surface defect near the first end of the tubular member and the method further comprising

transmitting a sonic beam from the transducers such that the sonic beam is reflected from the inner surface defect,

receiving the reflected beam from the inner surface defect of the tubular member,

producing a defect signal related to the sonic beam reflected from the inner surface defect, the defect signal for conveying information about the inner surface defect, and

transmitting the defect signal to signal analysis apparatus to analyze and indicate the inner surface defect.

Advantageously, an end signal related to a beam reflected from the first end of the tubular is produced, the end signal having information about the first end of the tubular member,

calculating an end distance from the transducers to the first end of the tubular member using the information of the end signal, and

until the end distance is less than a first pre-set value continuing to inspect the surfaces of the tubular member.

Preferably, until the end distance is less than a second pre-set value, continuing to inspect the outer surface of the tubular member.

Advantageously, the end distance is less than the second pre-set value, continuing to inspect the inner surface of the tubular member.

Preferably, the end distance is less than the first pre-set value, ceasing inspection of the inner surface of the tubular member.

Advantageously, the first pre-set value is one-eighth of an inch.

Preferably, the first pre-set value is two millimetres.

Advantageously, the inner surface defect is within two millimetres of the first end of the tubular.

Preferably, the inner surface defect is within one-eighth of an inch of the first end of the tubular.

Advantageously, substantially all of the entire surface of the tubular member is accurately inspected for inner surface defects.

Preferably, each transducer has associated instrumentation for controlling each transducer.

Advantageously, a programmable logic controller controls movement means that moves the tubular member during inspection of the tubular member and that moves the transducers with respect to the tubular member.

Preferably, a computer analyzes signal information and associated display apparatus displays inspection results.

Advantageously, relative helical motion is provided between the tubular member and the transducers to trace a helical path around the surfaces of the tubular member with the sonic beams.

Preferably, sonic beams are transmitted longitudinally and transversely through the member with the transducers.

Advantageously, sonic beams are transmitted longitudinally, transversely, and obliquely into the tubular member.

Preferably, the transducers are mounted on a waveguide support having a single beam passage area and the reflected beams bass through the single beam passage area.

Advantageously, a position of the transducers is tracked and a location signal indicative of said position is generated.

Preferably, relative motion between the tubular member and the transducers is stopped when said location signal indicates that the transducers are within a pre-set distance to an end of the tubular member.

Advantageously, movement of the tubular member is stopped by stopper apparatus.

Preferably, an end of the tubular member is sensed with end sensor apparatus and the end sensor apparatus sends an end signal to a control system that controls movement of the transducers, the method further comprising

receipt of the end signal by the control system, and

stopping movement of the transducers by the control system in response to the end signal.

Advantageously, the transducers are moved in indexed step increments.

Preferably, each indexed step increment of the indexed step increments is a fraction of a beam width of a sonic beam from the transducers.

Advantageously, the fraction is from the group consisting of 1/32, 1/16, 1/8, 1/4, and 1/2.

According to another aspect of the present invention there is provided a method for ultrasonically inspecting a tubular member, comprising

transmitting sonic beams through the tubular member with at least one transducer so that sonic beams are reflected from an inner surface of the tubular member, from an outer surface of the tubular member, and from defects of the tubular member, if any,

receiving with the at least one transducer reflected beams from the surface defects of the tubular member, if any, from the inner surface and from the outer surface of the tubular member,

sensing an end distance from the at least one transducer to an end of the tubular member, and

ceasing inspection of the tubular member when the end distance is less than a pre-set value.

According to another aspect of the present invention there is provided an ultrasonic inspection device useful for inspecting a tubular member comprising

transducers for transmitting sonic beams and for receiving reflected beams thereof from inner and outer surfaces of the tubular member, from ends of the tubular member including a first end spaced apart from a second end, and from defects of the tubular member,

the reflected beams including beams reflected from an outer surface of the tubular member, from an inner surface of the tubular member, from the first end of the tubular member, and from an inner surface defect of the tubular member, and

means for differentiating the reflected beams,

means for producing signals corresponding to information about the reflected beams, including a defect signal having information about the inner surface defect, and an end signal having information about the end of the tubular member, and

means for continuing inspection of the inner surface of the tubular member for inner surface defects until the end distance is less than a pre-set value.

The ultrasonic inspection device of claim 27 further comprising

means for ceasing inspection of the outer surface of the tubular member when all but about one-eighth of an inch of the tubular member's length has been inspected.

Preferably, the device has means for providing relative helical motion between the tubular member and the transducers to trace a helical path with sonic beams around the tubular member.

Advantageously, the device has means for indicating position of the transducers with respect to an end of the tubular member.

Preferably, the means for indicating the position of the transducers includes encoder apparatus.

Advantageously, the means for indicating the position of the transducers includes end sensor apparatus.

Advantageously, the device has means for energizing and de-energizing the transducers to sequentially transmit and receive sonic beams.

Preferably, the device has an array of opposing transducers for transmitting sonic beams, and

transducer positioning means to which the transducers are connected for positioning the transducers to transmit the sonic beams longitudinally, transversely, and obliquely through the tubular member such that beams are reflected from parts of the tubular member.

Advantageously, the device has a wall thickness transducer for measuring tubular member wall thickness.

Preferably, the device has a waveguide support apparatus supporting the transducers and having a single beam passage area through which all transmitted and reflected beams pass.

Advantageously, the device has means for moving the transducers in indexed steps with respect to the tubular member.

According to another aspect of the present invention there is provided a waveguide support for an ultrasonic inspection device useful for inspecting tubular members, the waveguide support for supporting a plurality of ultrasonic transducers, the waveguide support comprising

a body of waveguide material,

the body having a single beam passage area through which beams from all of the ultrasonic transducers are passable and back through which all beams reflected from the tubular member are passable back to the transducers.

Preferably, the support has a plurality of transducers on the body for transmitting sonic beams and for receiving reflected beams thereof from the tubular member.

Advantageously, the support has at least one transducer having a sensitive crystal area and

the single beam passage area slightly larger than the sensitive crystal area.

Preferably, the at least one transducer is a plurality of transducers each with a sensitive crystal area of substantially the same area.

According to another aspect of the present invention there is provided a method of ultrasonically inspecting a weld on a tubular member, the method comprising

transmitting sonic beams from ultrasonic transducers to inspect the weld,

receiving reflected beams from the weld, and

moving the ultrasonic transducers adjacent the weld in step-wise manner.

Advantageously, each transducer has associated instrumentation for controlling each transducer, and

a programmable logic controller controls movement means that rotates the tubular member with respect to the ultrasonic transducers and wherein movement means moves the transducers with respect to the tubular member.

Preferably, there are means for providing relative helical motion between the tubular member and the transducers to trace a helical path of sonic beams from the ultrasonic transducers around the tubular member, and means for indicating position of the transducers with respect to an end of the tubular member.

* * *

The present invention, in certain aspects, discloses a method for ultrasonically inspecting a tubular member, the tubular member having a first surface, a second surface, the first surface spaced apart from the second surface by a thickness of the tubular member, and two spaced-apart ends including a first end of the tubular member, the method including transmitting sonic beams to the tubular member with transducer apparatus such that sonic beams are reflected from the first surface of the tubular member and from the second surface of the tubular member, the transducer apparatus controlled by control apparatus, while continuing to inspect the first surface of the tubular member for first surface defects, moving the transducer apparatus adjacent sensing apparatus which signals the control apparatus to cease processing of transducer apparatus signals related to inspection of the second surface, and, the transducer apparatus continuing to transmit sonic beams for the inspection of the first surface of the tubular member, and completing inspection of the second surface of the tubular member for second surface defects while continuing to inspect the first surface of the tubular member for first surface defects.

The present invention discloses, in certain aspects, an ultrasonic inspection device useful for inspecting a tubular member including transducer apparatus for transmitting sonic beams and for receiving reflected beams thereof from inner and outer surfaces of the tubular member, and from defects of the tubular member, the reflected beams including beams reflected from an outer surface of the tubular member and from an inner surface of the tubular member, and from a defect of the tubular member, and apparatus for differentiating the reflected beams, apparatus for producing signals corresponding to information about the reflected beams, including a defect signal having information about the defect, and an end signal from proximity switch apparatus positioned with respect to an end of the tubular member, and apparatus for continuing inspection of one surface of the tubular member following cessation of inspection of the other surface of the tubular member.

The present invention, in certain embodiments, discloses a system for detecting defects in tubular members which is capable of examining almost all of the entire length of the tubular; and, in certain aspects, which can accurately detect flaws including inner surface defects in substantially all of a tubular's length and near or at its ends. In certain aspects this is accomplished with a system that nullifies, cancels, or ignores information from a signal reflected from a tubular end (or signals) - i.e. other than a signal or signals related to inner surface defects - transmitted to and reflected from the tubular. In many instances a signal reflected from a tubular end is misinterpreted as, is not easily distinguishable from or is indistinguishable from a signal reflected from an inner surface defect near a tubular end and such a signal often cannot be accurately analysed to determine whether there is a defect near the tubular end. A misinterpretation of such a signal can also result in a false indication of an inner surface defect.

According to yet another aspect of the present invention there is provided a method for ultrasonically inspecting a tubular member, the tubular member having a first surface and a second surface, the first surface spaced apart from the second surface by a thickness of the tubular member, and two spaced-apart ends including a first end and a second end of the tubular member, the method comprising

transmitting sonic beams to the tubular member with transducer apparatus such that sonic beams are reflected from the first surface of the tubular member and from the second surface of the tubular member, the transducer apparatus controlled by control apparatus,

while continuing to inspect the first surface of the tubular member for first surface defects, moving the transducer apparatus adjacent sensing apparatus which signals the control apparatus to cease processing of transducer apparatus signals related to inspection of the second surface, and, the transducer apparatus continuing to transmit sonic beams for the inspection of the first surface of the tubular member, and

completing inspection of substantially all of the second surface of the tubular member for second surface defects while continuing to inspect the first surface of the tubular member for first surface defects.

Advantageously, the first surface is a surface of an inner wall of the tubular member and the second surface is a surface of an outer wall of the tubular member.

Preferably, the first surface is a surface of an outer wall of the tubular member and the second surface is a surface of an inner wall of the tubular member.

Advantageously, the control apparatus comprises a logic control signal processing device.

Preferably, the sensing apparatus is a second proximity switch activatable by the presence of the transducer apparatus adjacent said proximity switch.

Advantageously, the sensing apparatus includes a first proximity switch for signalling the control apparatus to cease processing of transducer apparatus signals related to inspection of the first surface, the method further comprising

completing inspection of substantially all of the first surface of the tubular member for first surface defects.

Preferably, completion of inspection of substantially all of the tubular member for both first surface defects and second surface defects includes inspecting the tubular member's length up to a distance between one four and one sixteenth inches from each end of the tubular member, with the first and second proximity switches correspondingly positioned for said inspection completion.

Advantageously, the tubular member has a surface and the method further comprising

transmitting a sonic beam from the transducer apparatus such that the sonic beam is reflected from the inner surface defect,

receiving the reflected beam from the surface defect,

producing a defect signal related to the sonic beam reflected from the surface defect, the defect signal for conveying information about the surface defect, and

transmitting the defect signal to signal analysis apparatus to analyze and indicate the surface defect.

Preferably, the surface defect is a first surface defect.

Advantageously, the surface defect is a second surface defect.

Preferably, means are provided for producing an alarm when a flaw is detected, the method further comprising

providing an alarm when a flaw is detected.

Advantageously, the transducer apparatus has associated instrumentation for the transducer apparatus.

Preferably, a programmable logic controller controls movement means that moves the tubular member during inspection of the tubular member and that moves the transducer apparatus with respect to the tubular member.

Advantageously, associated display apparatus displays inspection results.

Preferably, the method further comprises the steps of:

providing relative helical motion between the tubular member and the transducer apparatus to trace a helical path around the surfaces of the tubular member with the sonic beams.

Advantageously, sonic beams are transmitted longitudinally and transversely through the member with the transducer apparatus.

Preferably, the sonic beams are transmitted longitudinally, transversely, and obliquely into the tubular member.

Advantageously, the transducer apparatus is mounted on a waveguide support having a single beam passage area and the reflected beams bass through the single beam passage area.

Preferably, a position of the transducers is tracked and a position signal indicative of said position is produced.

Advantageously, relative motion of the tubular member is stopped with a pipe stopper.

Preferably, the transducer apparatus includes multiple ultrasonic transducers.

Advantageously, the transducer apparatus is moved in indexed step increments.

Preferably, each indexed step increment of the indexed step increments is a fraction of a beam width of a sonic beam from the transducers.

According to another aspect of the present invention there is provided an ultrasonic inspection device useful for inspecting a tubular member comprising

transducer apparatus for transmitting sonic beams and for receiving reflected beams thereof from inner and outer surfaces of the tubular member, and from defects of the tubular member,

the reflected beams including beams reflected from an outer surface of the tubular member and from an inner surface of the tubular member, and from a defect of the tubular member, and

means for differentiating the reflected beams,

means for producing signals corresponding to information about the reflected beams, including a defect signal having information about the defect, and an end signal from proximity switch apparatus positioned with respect to an end of the tubular member, and

means for continuing inspection of one surface of the tubular member following cessation of inspection of the other surface of the tubular member.

Preferably, the device further comprises means for ceasing inspection of the tubular member when all but about one-eighth of an inch at one end of the tubular member's length has been inspected.

For a better understanding of the present invention reference will now be made by way of example to the accompanying drawings in which:

Fig. 1A is top perspective view from a first side of a first embodiment of a transducer device in accordance with the present invention;

Fig. 1B is top perspective view from a second side (opposite to the first) of the transducer device in Fig. 1A;

Fig. 1C is an underneath perspective view from the first side of the transducer in Fig. 1A;

Fig. 2A is a top perspective from the first side of a base for use in the device of Fig. 1A;

Fig. 2B is an underneath perspective view from the first side of the base in Fig. 2A;

Fig. 3A is a top perspective view of a wearplate for use in the device of Fig. 1A;

Fig. 3B is an underneath perspective view of the wearplate in Fig. 3A;

Fig. 4A is a top perspective view of a waveguide support for use in the device of Fig. 1A;

Fig. 4B is an underneath perspective view of the waveguide support of Fig. 4A;

Fig. 5A is a top plan view of a second embodiment of a transducer device in accordance with the present invention;

Fig. 5B is a cross section on the line 5B-5B of Fig. 5A;

Fig. 5C is a side view of the transducer device of Fig. 5A;

Fig. 5D is an underneath plan view of the transducer apparatus of Fig. 5A

Fig. 6A is a side view of a first embodiment of a tubular inspecting apparatus in accordance with the present invention with a tubular passing thereacross;

Fig. 6B is an end view of the apparatus and tubular of Fig. 6A;

Figs. 6C and 6D show a side view and an end view respectively of a second embodiment of a tubular inspecting apparatus similar to that in Figs 6A and 6B;

Figs. 6E and 6F show a side view and an end view respectively of a third embodiment of a tubular inspecting apparatus similar to that in Figs 6A and 6B;

Fig. 7 is a schematic diagram of the signal processing stages of a tubular inspecting apparatus in accordance with the present invention;

Fig. 8A is schematic view of a cross section through a pipe wall illustrating the path of ultrasound waves emitted from a transducer, together with graphs showing schematically the gates for receipt of reflected ultrasound signals from the sides and end of the pipe;

Fig. 8B shows the pipe wall of Fig. 8A with the transducer nearer to the pipe end;

Fig. 8C shows the pipe wall of Fig. 8A with the transducer nearer to the pipe end than in Fig. 8B;

Fig. 8D shows the pipe wall of Fig. 8A with the transducer nearer to the pipe end than in Fig. 8C;

Fig. 9A is a schematic side view of a fourth embodiment of a tubular inspecting apparatus in accordance with the present invention with a tubular positioned thereon;

Fig. 9B is a schematic view of part of the tubular inspecting apparatus of Fig. 9A;

Fig. 10A is a schematic cross section through a tubular wall showing the path of ultrasound therein emitted from a fifth embodiment of a tubular inspecting apparatus in accordance with the present invention;

Fig. 10B is the tubular wall of Fig. 10A showing the path of ultrasound when the transducer of the apparatus is nearer the pipe end than in Fig. 10A;

Fig. 10C is a schematic cross section through a tubular wall showing the path of ultrasound therein emitted from a sixth embodiment of a tubular inspecting apparatus in accordance with the present invention; and

Fig. 11 is a schematic diagram of the signal processing stages of a tubular inspecting apparatus in accordance with the present invention.

Figs. 1A - 1C show a transducer device 10 according to the present invention for use with tubular inspection apparatus. The device 10 has a base 12; a waveguide support 30; ultrasonic transducers 50a - 50d and 52 on the waveguide support 30; and a wearplate 20 secured over one surface of the waveguide member 30. Each transducer 50a - 50d has an ultrasound beam width of 0.5″ (1.0″ can be used alternatively).

Figs. 2A and 2B show details of the base 12 of the device 10 of Fig. 1. The base 12 has a body 14 with a recess 16 in which is positioned the waveguide support 30. A bevelled opening 11 receives a correspondingly shaped part of the waveguide support 30 as described below. A roller assembly is secured to the base 12 and has rollers 15 secured to a spacer 19 by bolts 17. These rollers 15 contact the outer surface of a tubular along which the device 10 is moved.

Figs. 3A and 3B show the wearplate 20 which has a body 22; front face 21; a bevelled opening 27 corresponding in size and location to the opening 11 of the base 12 and through which projects part of the waveguide support 30 as discussed below; and a rear face 23. The front surface 21 of the wearplate 20 is curved to correspond to the curved surface of a tubular being inspected with an apparatus provided with a device 10 (Fig. 1A). The wearplate 20, in certain embodiments, is made of polytetrafluoroethylene.

Figs. 4A and 4B show the waveguide support 30 of the device 10 of Fig. 1A. The transducers shown in Figs. 1A and 1B have been deleted from Figs. 4A and 4B. The waveguide support 30 has a body 32 with four spaced-apart pillars 31, each with a hole 33 in it for securing to the base 12. The body 32 has four inclined surfaces 35 to which are secured transducers 50 (see Fig. 1B). The transducers may be coupled with gel or other suitable material and/or held in place with screws or bolts using holes 39. A top surface 34 of the body 32 may be vacant or, optionally, a transducer 52 (see Fig. 1B) may be secured there. A lower member 36 projects down from the body 32. The lower member 36 may have a lower curved portion 37 whose shape corresponds to that of the front surface of the wearplate and to the tubular's outer surface.

The distance "d" in Fig. 1A is the distance from the transducer 50a to the front end of the base 12. In certain aspects the base 12 is moved so that the shoe progresses no further than the distance "d" to the end of the tubular being inspected. In other aspects the shoe is moved so that the opening 27 is beneath the end of the tubular. In other aspects the shoe is moved past the tubular end. In one particular embodiment the distance "d" is about one inch. In certain aspects the opening 27 (and the opening in any version of such a shoe) is about the same size as, is no less than in size, is between 5% to 30% larger in size than, or is about 20% larger in size than the sensitive area of a crystal of an ultrasonic transducer positioned near the opening.

In one embodiment the transducers (e.g., transducers as in Fig. 1A) in a device are so positioned and the waveguide support (e.g., the waveguide support 30) is so sized and configured with its surfaces and dimensions so that all beams, both initial transmitted sonic beams from the transducers and beams reflected from a tubular surface or from a flaw, pass through a single beam passage area (e.g. like the area between the lower member 36 of the waveguide support 30 and through opening 27 of the wearplate 20 and opening 11 of the base 12). In certain aspects the extent of the single beam passage area according to the present invention is slightly larger than the size (e.g., the area) of the sensitive area of the ultrasonic crystal of a transducer. In certain aspects the size of the single beam passage area is between 105% to 125% (or more) of the size of the transducer crystal's sensitive area and in one particular aspect the size of the area is 120% of the size thereof.

Figs. 5A - 5D show a transducer device 100 that has a body 102 to which are secured multiple transducers 106 and an optional transducer 104. Each transducer 106 is mounted in a corresponding recess 107 in the body 102. The transducer 104 is mounted in a recess 108. The body 102 may be made of aluminium, of another suitable metal, of Lucite (trademark) plastic or of similar plastic or material. The angle α shown in Fig. 5B is 18.8°.

A bladder 120 is secured over a recess 114 in the body 102. Optionally a ring (not shown) may be used to hold the bladder in place. Screws through the ring pass into the holes 115 to hold the ring securely to the body 102. Holes 112 provide for the flow of fluid to and from the bladder 120 directly from the holes 112 into the bladder so that the shape of the bladder 120 is adjustable to conform to the shape of a pipe P that is being inspected.

A "single area" 110 between the transducers 106 provides an area through which both transmitted and reflected sonic beam(s) pass.

Figs. 6A, 6C and 6E show schematically three embodiments of tubular inspection apparatus each of which uses a transducer device 10 and/or 100 to inspect tubulars.

Figs. 6A and 6B show a tubular inspection apparatus 160 that has a pipe rotation system 162 for radially rotating a pipe 161 and a sensing system 170 which includes a transducer system 171 with a "shoe" 172 with a plurality of transducers (e.g. but not limited to as in the systems of Fig. 1A and 5A). Water is supplied to the transducer system 171 by a water supply system 174. A shoe movement system 176 for moving the shoe 172 axially with respect to the pipe 161 includes a mount 177 that is moved on a precision linear motion table 178 by a motor 179. A mounting bracket 164 supports a ball/screw apparatus 163 (optionally with a tracking encoder apparatus 166) that is moved by the motor 179. A water tray 165 is positioned below the shoe 172. A programmable logic controller (hereinafter "PLC") 173 controls the motor 179 and, if desired, the rotation system 162.

Figs. 6C and 6D show a tubular inspection apparatus 180 like the system 160 of Fig. 6A (like numerals indicate like parts); but the system 180 has an end sensor 182 which senses an end of the pipe 161 and produces an electronic signal which is transmitted by the end sensor to the PLC 173. In response to this signal, the PLC 173 decouples the transducers from the pipe 161 (i.e. moves the shoe away from and out of contact with the pipe 161). The system 180 also has a physical pipe stopper 184 that prevents further movement (to the right in Fig. 6C) of the pipe. When the pipe stopper 184 stops the pipe 161 the shoe 172 is in a known position with respect to the end of the pipe 161. The PLC and/or the transducer system are interconnected with a computer or computers and/or monitors and/or display apparatus (e.g. as in Fig. 6E).

Figs. 6E and 6F show a show a tubular inspection apparatus 200 which, in some respects, is similar to the systems of Figs. 6A and 6C (like numerals indicate like parts). A pipe 161 to be rotated and inspected is radially rotated by a rotation system 162 while a transducer system 171 for inspecting the pipe 161 is moved adjacent the pipe 161. A powered conveyor roller 216 (or rollers) moves the pipe 161 axially (left and right in Fig. 6E) away from or toward a pipe stop 218. A water supply system 174 sprays water onto a shoe 172 of the transducer system 171 to provide water coupling between the shoe and the pipe to assist the transmission of ultrasonic signals to and away from the transducer system.

A water cleaning tray 222 receives excess water expelled by the shoe 172 for disposal or for recycling in the system. Optionally, the tray 222 is removable for cleaning dirt, debris, etc. accumulated therein. A compliant mount/suspension system 202 provides apparatus for raising and lowering the shoe 172 and a flexible support for the shoe 172 to accommodate irregularities and eccentricities in the pipe 161 as it is rotated adjacent the shoe 172. Any suitable known pipe rotation system may be used for the system 162. An optional pneumatic lift 204 raises the shoe 172 to contact the pipe 161 and lowers the shoe 172 to facilitate pipe loading or unloading. The lift 204 is controlled by the PLC 173. Hose and cable management apparatus 206 holds and accommodates various items - cables, wires, hoses, etc. - associated with the provision of water, electrical power, and signals to the various parts of the table 214 and parts of the system 200 (and such apparatus 206 may be used in the systems of Figs. 6A and 6C). All mechanical functions of the system are controllable by the PLC 173.

A drive motor 208 mounted to the end of a ball/screw apparatus 212 moves the shoe 172 axially along the pipe

161. The ball/screw apparatus is part of a precision linear motion table 214 that accurately and precisely, and with stability, moves the transducer system 171 with respect to the pipe 161. The ball/screw apparatus 212 provides a linear drive for the movement of the shoe 172 along the pipe 161; and the encoder 210, attached to the ball/screw apparatus, provides location feedback information to the PLC 173. Accordingly when the pipe is positioned adjacent the pipe stop, the location of the transducer with respect to the end of the pipe is known by reference to the position of the transducer with respect to the linear motion table. The PLC 173 and the ultrasonic transducers of the transducer system 171 provide data to a computer 220. The computer 220 is interconnected with either a monitor (or monitors) 221 and/or a strip chart recorder (or recorders) 223 to display inspection results. In one aspect inspection results are displayed to system operators in real-time. Also the computer 220 may, in certain aspects, be programmed to provide an alarm signal to a PLC to activate an alarm when a flaw is detected. There may be an alarm in or on the computer itself. Also, a known precision linear motion table may be used for the table 214.

An end sensor 182 senses the location of the shoe 172 with respect to the end of the pipe 161 and senses the location of the end of the pipe 161 when the transducer system 171 nears the pipe end (the end to the right in Fig. 6E).

Referring to Fig. 7 transducers 151 - 154 and 155 - each with corresponding associated instrumentation 151a - 154a - correspond to the transducers 106 and 104, respectively, of the system 100 (Fig. 5A) or to the transducers 50a - 50d and 52, respectively of the system 10 (Fig. 1A). The transducers 151 - 154 are for flaw detection and the transducer 155 is for measuring tubular member wall thickness. Ultrasonic electronic instrumentation is used which provides for the measurement of the amplitude of reflected sonic beams and the measurement of the time of flight of sonic beams to indicate , locate, and measure I.D. flaws, O.D. flaws, wall thickness, and time of flight to the end of a tubular member. The instrumentation also receives an interface signal that indicates the interface between a transducer and the tubular member as each firing sequence is initiated.

Each transducer is controlled by its associated instrumentation so that it transmits its sonic beam at specified time intervals at a specified repetition rate for a specified time duration, e.g., in some systems it may range between 50 milliseconds and a second. By imposing these electronic time data correction windows or "gates" ("Interface Gate") on the transducers' operation, the instrumentation permits the collection and processing of output signal information only in the specified time windows. The gates provide a reference frame by which the location of a defect from the electrical output signal from the transducers can be determined. Thus if a flaw is indicated by a reflected signal, the location of the flaw is known. Each transducer can be used for both I.D. and O.D. flaw detection and for pipe end indication. A "Transverse Front" transducer faces the front of the tubular member (e.g., transducer 50a in Fig. 1A) and a "Transverse Back" transducer faces the back of the tubular member (e.g., transducer 50b in Fig. 1A). A "Longitudinal Left" transducer faces to the left (e.g., transducer 50c in Fig. 1A) and "Longitudinal Right" transducer faces to the right (e.g., transducer 50d in Fig. 1A).

A reflected beam is received back by a transducer following reflection from an end of the tubular or from a flaw at a surface; and the transducer then senses and receives an echo (reflected beam) which has an amplitude. If the echo is relatively small (i.e. with little or no amplitude), no flaw is indicated; if the echo has an amplitude that exceeds a pre-set value (programmed in the computer 156) then a flaw ("ID/OD Flaw") is indicated. Optionally the computer 156 produces a flaw alarm signal ("flaw alarm"; sound and/or visual). Flaw location and size are determined and are displayed by the computer 156. The transducer instrumentation for the transducer 155 produces a time of flight measurement (time of flight of a compressional wave packet from the interface, to the I.D. and back to the transducer) indicative of tubular wall thickness ("wall thickness") which is transmitted to the computer 156 (as digital information from the ultrasonic instrumentation) for wall thickness determination, alarm if necessary, and/or display.

When the transducer device nears the end of the pipe, a beam from the front transducer (e.g. 50a in Fig. 1A) reflects from the tubular end. Upon receipt of the beam reflected from the tubular end, the system calculates the distance from the front transducer to the end of the tubular (e.g. by using the time duration between an initial interface pulse and the time of the pulse reflected from the tubular end). The calculated distance-to-the-end of the tubular indicates if the transducer is at or near the end of the tubular member. If desired to distinguish the pipe end signal from a defect signal the apparatus makes a separate measurement of the distance between the transducer and the pipe end. This distance can be converted into a time of flight for ultrasound in the material of the pipe. By measuring the time of flight of signals transmitted into the pipe it is possible to identify a time window or gate in which sound reflected from the pipe end should be received. If a signal is received in this gate it is assumed to originate from the pipe end. When the front transducer has reached a position at which the system knows that substantially the entire outer surface of the tubular has been inspected - a position near the tubular end at which part of the inner surface between the front transducer and the end of the tubular has not yet been inspected - the system continues with the inner surface inspection, ignoring any signal which may be received for time periods which would correspond to further outer surface inspection if the tubular end was not present; and while this inner surface inspection continues the system continuously detects and calculates the distance to the tubular end so that inner surface inspection is stopped when the front transducer's I.D. beam width reaches the tubular end. Due to the way in which the tubular member is rotated, the outer surface of the tubular member is completely examined - i.e., sonic beams are reflected from the entire outer surface - before the inner surface is completely examined, or *vice versa*. Therefore, the system, in certain aspects, ignores signals and their information related to any reflected beam other than those related to inner surface (or outer surface) examination and end-reflected beams at a pre-set position of the transducer device.

The device 156 may include: a screen (or screens) (or strip chart apparatus) that displays a graphical representation of a tubular being examined, in one aspect in cross-section, with initial interface, end reflections, surface reflections, and flaw reflections; a computer (or computers) for analysing the various signals from the transducers and/or from the PLC, e.g. to determine transducer location, tubular end location, wall thickness, defect existence, defect location, defect orientation and defect signal amplitude; and, if determined, for sending an alarm regarding insufficient wall thickness or defect indication; and for generating a report to or display for an operator which may be an interactive display to facilitate operational control of the system. Flaw location may be displayed in a two-dimensional display in which the horizontal axis is the tubular length and the vertical axis is the tubular's circumference; or flaw-reflected signal amplitude may be displayed as a function of tubular length on a strip chart. Display of the results of the tubular examination, and flaw display, may be done (with any system disclosed herein) in "real time" so that an operator sees (or is aware) of the detection of a defect as soon as the defect is detected.

Optionally, a computer of the system has a "GO/NO GO" capability with which it compares flaw signal amplitude to a pre-set threshold - based on an acceptable or unacceptable size flaw. The system then indicates whether the flaw renders the tubular acceptable or unacceptable. Similarly, the computer compares the amplitude of the wall thickness signal to a pre-set value to determine if the wall thickness is acceptable.

A PLC 157 (e.g. like that of the systems of Figs. 6A, 6C, 6E) is interconnected electronically with: a computer; a motor like the motor of the systems of Figs. 6A and 6C for moving the transducer system longitudinally with respect to a tubular to be inspected; the device 157 for providing information to the computer 156 regarding the location, both longitudinally ("Head Linear Location") and circumferentially ("Head Circumferential Location"), of the transducer system; a tubular rotation system ("Pipe Rotation Control") for controlling pipe rotation; an end sensor, like those of the systems of Figs. 6A, 6C, and 6E, for receiving from the end sensor a signal indicative of transducer system location ("Pipe End Photocell") in reference to the tubular end; a mechanical and/or electronic and/or electromagnetic device or apparatus ("Encoder") that indicates location of the transducer system with respect to the end of the tubular; system for indicating each rotation of the tubular, e.g. a magnetic tubular sensing system or a light sensing system with a photocell that indicates each rotation of the tubular (e.g., in one aspect by sensing a reflective area on the tubular each time it rotates past a photocell, e.g. a reflector or reflective tape or paint at a 12 o'clock position on the tubular) ("12:00 Prox"). In one particular aspect the PLC 157 activates the motor that moves the transducer system ("head") in steps so that the end part of the tubular is examined (with the transducers stationary between steps and the tubular still rotating through 360 degrees for each step as described above). In other aspects the motor itself includes apparatus that activates the motor in steps (in one aspect commonly called a "Stepping Motor"), so that a full and complete inspection of a tubular is obtained, e.g. a shoe, for each rotation of the pipe, is indexed in steps or advanced in increments that are a fraction of the transducer beam width (e.g., but not limited to, 1/32, 1/16, 1/8, 1/4, 1/2). In one particular embodiment the a shoe is indexed in one 3mm step for every rotation of the tubular. If the shoe is moved continuously with respect to a rotating tubular a helical path is traced resulting in some areas that are not always thoroughly inspected. By moving the shoe in steps this effect can be inhibited.

Figs 8A - 8D illustrate the operation of an automated tubular inspection apparatus (like any of the apparatus described herein) and show the end and near-end inspection of a tubular ("pipe") with an ultrasonic transducer system.

As shown in Fig. 8A a front transducer ("UT TRANSDUCER") adjacent an outer surface ("OD") of a tubular member ("PIPE") at a specific time (horizontal axes are time axes) has fired an ultrasonic pulse ("SOUND BEAM") at 45° into the pipe a shear wave packet that has twice hit the pipe's inner surface ("ID"), once hit the pipe's outer surface, and has hit the end of the pipe at the outer surface ("END OF PIPE"). Having moved from left to right, at this location the transducer has examined substantially the entire outer surface of the pipe (i.e., probed with a sonic beam); and a portion "a" of the pipe's inner surface has not yet been inspected. The sonic beam from the transducer follows the indicated path in both transmission and reflection. The transducer sends a sonic beam (a shear wave packet) directly across the pipe (upwards in Fig. 8A) which reflects back to the transducer from the pipe ID, producing the "INTERFACE SIGNAL" which indicates the transducer's location at the time of the sonic beam shown in Fig. 8A on the lowermost "TIME" axis. The reflection back from the end of the pipe produces "PIPE END SIGNAL" shown on the lowermost time axis. The time differential between the interface signal and the pipe end signal provides the basis for calculating the distance from the transducer to the end of the pipe. The computer using the speed of the sonic beam and the elapsed time between signals determines the distance to the pipe end. As mentioned above, if it is desired to distinguish the pipe end signal from a defect signal the distance between the transducer and the pipe end can be measured by the apparatus. This distance is converted to a time gate, timed from emission of the ultrasound, within which the pipe end signal will be received by the transducer. Accordingly, the apparatus is able to discount signals received within this gate so that no flaw alarm is generated erroneously. The transducer instrumentation is programmed with various time windows ("GATES") in which the transducer is activated to receive echoes from specific places; the "INTERFACE GATE" is a pre-set time window during which the transducer is operational for receiving the interface signal; the "ID GATE" is a pre-set time window pre-set for a specified time after the interface signal during which the transducer is operational for receiving an echo from the pipe ID of the sonic beam's first hit on the pipe ID following transmission of the sonic beam from the transducer; the "OD GATE" is a pre-set time window pre-set for a specified time after the interface signal during which the transducer is operational for receiving an echo from the sonic beam's first hit on the pipe OD; and the "PIPE END GATE" is a pre-set time window during which the transducer is operational for receiving an echo from the pie end.

As shown in Fig. 8A, the sonic beam has encountered no tubular defect at either pipe surface and no defect signal is indicated on lowermost time axis. Any defect within the ID GATE or OD GATE would have resulted in the production of a signal with amplitude above that of the lowermost time axis.

The temporal duration of the three gates shown in Fig. 8A is based on the velocity of sound through the material of the particular tubular member and its wall thickness. An operator inputs these parameters in the PLC that then electronically calculates the duration and position of the gates in time to be applied to the output signal. Any defect signal received in the PIPE END GATE is dismissed. Accordingly in Fig. 8A the transducer can only detect flaws just beyond the limit of the O.D. gate. It is possible to set the PIPE END GATE in a different position, for example after the third leg of the sound beam. If this were done inspection of the inner surface would be completed before the outer surface.

As shown in Fig. 8B the transducer has moved closer to the pipe end; except for the length "b", the pipe's inner surface has been inspected; except for the length "c" (which is less than the length "b") the pipe's outer surface has been inspected; and no defect has been detected. The PIPE END SIGNAL indicates that the transducer is a distance "d" from the pipe end. As the transducer moves toward the pipe end the O.D. gate moves closer to the PIPE END GATE, which is also moved toward the pipe end. Due to resolution constraints, for example the width of the ultrasound pulse from the transducer, it is difficult to measure to the end of the pipe and accordingly there is a limit to which how close the PIPE END GATE can be moved toward the pipe end. Typically it is possible to inspect to approximately 2-3mm from the pipe end.

As shown in Fig. 8C, substantially the entire pipe outer surface has been examined; a length "e" of the pipe's inner surface has not yet been examined; and the transducer is a distance "f" from the pipe end. The PIPE END GATE has been moved toward the I.D. gate. Signals from the O.D. gate are not originated by an O.D. flaw and are, therefore ignored; i.e., the system has moved the pipe end gate to overlap the O.D. gate so as to effectively ignore any signals generated by the pipe end which might otherwise be interpreted as an indication of an O.D. flaw. O.D. examination has been completed - there is no more pipe outer surface to be examined, no more pipe outer surface past (to the right in Fig. 8C) the pipe end.

As shown in Fig. 8D, once substantially the entire outer surface has been inspected (shown in Fig. 8C) the transducer continues to move toward the pipe end transmitting the sonic beam to inspect the remaining portion (length "e") of the inner surface while continuously receiving the end signal that indicates that the transducer is getting closer and closer to the pipe end. The resolution of inspection is similar to that described in connection with Fig. 8B. Thus, the inspection of substantially the entire inner surface is completed; at which point the pipe end signal indicates that the transducer is at the end of the pipe and the system moves the transducer system away from the pipe (decouples it).

In order to accurately ascertain the distance to the end of the pipe, to finish and complete the pipe I.D. inspection, and to insure that the pipe end is sensed when the transducer moves to a point adjacent the pipe end, the PIPE END GATE is moved so that it begins immediately after the completion of the ID GATE. The movement of the shoe with the transducers is halted when the inspection has been completed.

The "UNINSPECTED LENGTH" in Fig. 8D indicates the length of the I.D. that has not yet been inspected due to the limitations of distinguishing a relatively small flaw signal from a relatively large end signal.

For illustrative purposes a flaw signal FS is shown on Fig. 8D whose amplitude (height in Fig. 8D above the lower most time axis) is less than the amplitude of the INTERFACE SIGNAL and less than the amplitude of the PIPE END SIGNAL. The amplitude of the flaw signal FS can provide a defect indication which indicates that a defect of such extent is present that the pipe may be rejectable; i.e. the amplitude exceeds a threshold amplitude (an amplitude initially calibrated for flaws from a fixed known reference flaw). In one aspect this threshold amplitude is the height of the I.D. gate. The system provides an alarm as discussed above when there is a defect indication and/or optionally provides a "NO GO" indication for the rejection of the tubular being examined.

Fig. 9A shows a tubular inspection apparatus 250 that is like other tubular inspection apparatus described herein, e.g. like the apparatus of Fig. 6A, 6E and 8A, and parts like those of the apparatus of Fig. 6A have like numerals. However, the apparatus 250 has one or two proximity switches 251, 252 (or photocell sensor apparatus) that are activated by passage of a UT transducer system 271 [and its accompanying instrumentation 253 (like instrumentation 151a - 155a, Fig. 7] for providing ID and OD flaw inspection (like, e.g., the transducer system 171, Fig. 6A) near the proximity switches. Alternatively, rod, beam or other suitable member 255 (see Figs. 10A, 10B) connected to the UT transducer system 271 is located so that the rod 255 moves adjacent the proximity switch(es), thereby activating it or them so that it or they send a signal to the PLC 173 (not shown) to stop inspection of the OD or ID, respectively, of a pipe 161 being inspected. It is to be understood that other components of an apparatus like that described above (e.g. Figs. 6A - 7) are present for the system 250 (e.g., but not limited to pipe rotation apparatus, like the system 162, Fig. 6A; sensing system, like the system 170, Fig. 6A; water supply system, like the system 174, Fig. 6A; transducer instrumentation apparatus; shoe and shoe movement system, like the shoe 172 and system 176, Fig. 6A; mount and precision linear motion table, like the mount 177 and table 178, Fig. 6A; etc); but the computer 156 is deleted and no sensing of the distance to the end of the pipe is done (since the "ID PROX" proximity switch signals when the UT transducer is at a point at which ID inspection can cease. Alternatively a drive motor/drive shaft apparatus may be used to move the UT transducer system.

As shown in Fig. 9B, the location of the UT transducer 271 is controlled by the PLC 173. Any desired number of UT transducers may be used (e.g., but not limited to, ten transducers on a waveguide or shoe). Upon receipt of a signal from the OD proximity switch 251 that it has sensed the UT transducer 271 (or a rod 255 extending therefrom as illustrated in Fig. 10A), the PLC discounts OD signals from the UT Instrumentation 253 and thus inspection of the OD of the pipe 161 ceases (e.g. within a preset distance of the pipe end, e.g. within one-eighth or one sixteenth inch of an end of the pipe - and the apparatus, as any herein, can inspect up to such a distance with respect to both ends of a pipe). The OD proximity switch 251 is located at a position corresponding to a location past which the UT transducer 271 would inspect an end portion of the pipe 161, e.g., as shown, the last inch of the pipe, although in other embodiments the OD proximity switch may be located any desired distance from the pipe end, including, but not limited to, ¼ inch or 1/16 inch. This location can take into account the "footprint" or width of the ultrasonic beam being used, which in some embodiments is 0.5″ or 1.0″. An OD flaw signal from the UT instrumentation will be discounted by the PLC 173 once the OD proximity switch 251 has sent its signal (or in other aspects in which an ID proximity switch is first encountered, an ID flaw signal will be discounted by the PLC). A pipe stopper 284 physically stops the pipe 161.

After the OD inspection ceases, ID inspection continues until, as shown in Fig. 10B, the rod 257 moves adjacent the ID proximity switch 252 at which point it sends a signal to the PLC 173. The PLC 173 then discounts further ID signals from the UT Instrumentation upon movement of the UT transducer 271 back to an initial position adjacent a "START" proximity switch 258. The PLC is signalled so that it knows that the UT transducer 271 is again in position to start an inspection.

Optionally, an alarm (audio and/or visual) may be interconnected with the PLC for activation upon receipt of a flaw signal (provided that the proximity switch has not been encountered). As shown in Fig. 9B an audio alarm 259 provides a sound alarm upon receipt of a flaw signal. "START PROX" in Fig. 9A and 9B indicate a proximity switch (or photocell) at the beginning of the travel of the UT transducer 271. If an OD or an ID flaw is detected by the system 250 between the starting proximity sensor ("START PROX") and the OD proximity switch 251 and ID or OD alarm signal is sent to the PLC 173 and a corresponding alarm signal is sent from the PLC to the alarm 259 and an audio alarm is sounded (or alternatively a flashing light is used). If an ID flaw in the pipe 161 is sensed between the OD proximity sensor and the ID proximity sensor, an ID alarm signal is sent by the UT instrumentation 253 to the PLC 173 and an ID flaw alarm is generated. Any system according to the present invention may employ an ID proximity switch, an OD proximity switch, or both, with or without corresponding rods 255, 257. Any alarm herein may also indicate and differentiate between an ID flaw and an OD flaw.

As shown in Fig. 10A, the OD proximity switch 251 can be located so that an ultrasonic pulse 277 from the UT transducer 271 is reflected from the ID wall of the pipe 161 and then hits an OD notch 256 which is a desired distance from the end of the pipe (e.g. 1/8" as shown, or, preferably, between ¼" and 1/16"). The OD notch 256 is made in the pipe prior to inspection. Similarly, as shown in Fig. 10B, the ID proximity switch 252 can be located with respect to an ID notch 253 so that an ultrasonic pulse 278 from the UT transducer 271 hits an ID notch 253 (made in the pipe prior to inspection and located a desired known distance from the pipe end - as shown, 1/8"). Thus the ID and OD notches are, in effect, detectable artificial flaws positioned in a known location.

As shown in Figs. 10A and 10B, for OD notch detection the ultrasonic pulse is reflected once (Fig. 10A) from the pipe ID wall before it contacts the OD notch (the pulse has two "legs") and the ultrasonic pulse is not reflected (Fig. 10B) from the pipe wall before it hits the ID notch (the pulse has one "leg"); but, it is within the scope of the present invention (for any system and method disclosed herein) to use a multi-legged pulse (e.g. three, five, or more legs) for contacting the ID notch and a multi-legged pulse (e.g., two, four, six or more legs) for contacting the OD notch. The location of the ID notch and/or OD notch is adjusted depending on the number of reflections (legs) used and thus the ID proximity switch and/or OD proximity switch will have a corresponding location with respect to the pipe end (a location corresponding to the location of the UT transducer when it emits the known multi-leg pulse). When the transducer passes the ID and/or OD proximity switch the PLC instructs the transducer to transmit an ultrasonic pulse. If the pipe is in the correct position i.e. the notch is the correct distance from the transducer, the transducer will receive the reflected waves in a predetermined time window. Receipt of a signal by the PLC in this time window confirms correct positioning of the pipe, and hence the position of the transducer with respect to the end of the pipe is known. This then allows the pipe end gate, ID and OD gates to be set appropriately for further inspection It should also be noted that it is possible to have the UT transducer first encounter an ID proximity switch prior to encountering an OD proximity switch. For example, as shown in Fig. 10C, the UT transducer encounters an ID proximity switch 252a prior to encountering an OD proximity switch 251a - and the ultrasonic pulse from the UT transducer 271 that contacts the ID notch 253a and which is reflected once from the pipe ID wall 161a and once from the pipe OD wall 161b (i.e., the pulse has three "legs"). As shown in Fig. 10C the ultrasonic pulse from the UT transducer when it is adjacent the OD proximity switch 251a will have two legs, but, as described above, a multi-legged pulse of four or more legs may be used for OD notch detection with the OD proximity switch located appropriately. It is within the scope of the present invention to use such multi-legged pulses for any system according to the present invention, including, but not limited to, those referred to with respect to Figs. 6A, 6E, 7, 8A, and 9A. The number of legs will depend upon the preset distance(s) between the ID, OD sensors, the notch and on the angle at which the ultrasound is transmitted into the pipe.

Fig. 11 shows schematically an instrumentation/control diagram for a system like the apparatus 250 like that of Fig. 9A which has no computer 156 (like that in Fig. 7) and in which no signal related to distance-to-end-of-pipe is sent by a UT transducer to a PLC. The system shown in Fig. 11 has four transducers 271 (the top four) and a wall thickness transducer 275 each with corresponding instrumentation 253, 276, respectively. It is within the scope of this invention to use any suitable known logic control signal processing device for the PLC.

It is to be noted that increasing the frequency of the ultrasound used allows inspection of the product nearer to the end. It has been found the method and apparatus work well on tubulars when the transducer moves toward each end. The methods and apparatus as described herein are particularly useful for inspecting tubulars to be used in the oil and gas industry. However, the method is also applicable to other areas, for example inspecting sheet and plate goods.

Claims:

1. A method of inspecting a product with ultrasound, which method comprises the steps of:

(a) transmitting ultrasonic waves into the product with a transducer means such that they are internally reflected from a first surface, a second surface, and from an end of the product;

(b) receiving ultrasonic waves reflected from the end of the product and from any defects in the first and second surfaces;

(c) generating a position signal representative of the position of the transducer means with respect to said end;

(d) using said position signal to enable inspection of substantially the entire first surface of the product, while continuing to inspect the second surface of the product; and

(e) thereafter disregarding any indication of a defect in said first surface while using said position signal to enable inspection of substantially the entire second surface of the product.

2. A method as claimed in claim 1, further comprising the steps of establishing (i) a first time gate in which waves reflected from any first surface defects are expected to be received, (ii) a second time gate in which waves reflected from any second surface defects are expected to be received, and (iii) a product end gate after or during which waves reflected from said end are expected to be received; and applying said gates to an output signal from the transducer means.

3. A method as claimed in claim 2, further comprising the step of positioning said product end gate substantially directly after said second time gate irrespective of said distance.

4. A method as claimed in claim 1, 2 or 3, further

comprising the steps of inspecting the first and second surfaces until said position signal reaches a first predetermined threshold, ceasing inspection of said first surface and continuing inspection of said second surface.

5. A method as claimed in claim 4, wherein said first predetermined threshold corresponds to a distance at which substantially all of said first surface has been inspected.

6. A method as claimed in claim 4 or 5, further comprising the step of overlaying the product end gate over the first time gate so as to substantially discount and defect signals reflected from the first surface.

7. A method as claimed in claim 4, 5, or 6 further comprising the step of ceasing inspection of said second surface when said position signal reaches a second predetermined threshold, smaller than said first predetermined threshold.

8. A method as claimed in claim 7, wherein said second predetermined threshold corresponds to a distance at which substantially all of said second surface has been completed or as much as is possible taking into account a beam width of the ultrasonic waves emitted from the transducer means.

9. A method as claimed in any of claims 2 to 8, further comprising the steps of moving the transducer means toward the end, and moving said first time gate, said second time gate and said product end gate toward said end nearer in time to transmission of said ultrasonic waves.

10. A method as claimed in any preceding claim, wherein step (a) is performed by transmitting ultrasonic waves longitudinally and transversely into said product.

11. A method as claimed in any preceding claim, further comprising the step of transmitting ultrasonic waves obliquely into the product.

12. A method as claimed in any preceding claim, wherein said transducer means comprises a plurality of transducers, and step (a) is performed by transmitting and receiving ultrasonic waves through a single beam passage area in a body on which said transducers are mounted.

13. A method as claimed in any preceding claim, further comprising the steps of positioning the product at a predetermined location at which the position of the transducer means with respect to said end is known, and providing a reference signal from which said distance can be determined.

14. A method as claimed in any preceding claim, further comprising the step of moving said transducer means with respect to the product in indexed step increments toward said end.

15. A method as claimed in claim 14 wherein each indexed step increment is a fraction of a beam width of the transducer means.

16. A method as claimed in any preceding claim, further comprising the steps moving said transducer means toward the end, generating a first proximity signal when the transducer means passes a first predetermined location, and ceasing inspection of said first surface in response to said first proximity signal.

17. A method as claimed in any preceding claim, further comprising the steps moving said transducer means toward the end, generating a second proximity signal when the transducer means passes a second predetermined location, and ceasing inspection of said second surface in response to said second proximity signal.

18. A method as claimed in any preceding claim, further comprising the steps of providing a first man-made defect in the product, identification of waves reflected from said first man-made defect at a predetermined location of

the transducer means ceasing inspection of the first surface within a predetermined distance of the end.

19. A method as claimed in any preceding claim, further comprising the steps of providing a second man-made defect in the product, identification of said second man-made defect at a predetermined location of the transducer means ceasing inspection of the second surface within a predetermined distance of the end.

20. A method as claimed in any preceding claim, wherein said product is a tubular, sheet or plate.

21. A method as claimed in claim 20, wherein said first surface is an outer surface of said tubular, sheet or plate, and said second surface is an inner surface of said tubular, sheet or plate.

22. A method as claimed in claim 20, wherein said first surface is an inner surface of said tubular, sheet or plate, and said second surface is an outer surface of said tubular, sheet or plate.

23. An apparatus for inspecting a product with ultrasound, which apparatus comprises:

(a) transducer means for transmitting ultrasonic waves into the product such that they are internally reflected from a first surface, a second surface and an from end of the product;

(b) means for receiving ultrasonic waves reflected from the end of the product, and any defects in the first and second surfaces;

(c) generating means for generating a position signal representative of the position of the transducer means with respect to said end;

the arrangement being such that, in use, said position signal is used to enable inspection of substantially the entire first surface of the product, while continuing to inspect the second surface of the product, and thereafter any indication of a defect in said first surface is disregarded while using said position signal to enable inspection of substantially the entire second surface of the product.

24. An apparatus as claimed in claim 23, wherein, in use said processing means establishes (i) a first time gate in which waves reflected from any first surface defects are expected to be received, (ii) a second time gate in which waves reflected from any second surface defects are expected to be received, and (iii) a product end gate after or during which waves reflected from said end are expected to be received; and applies said gates to an output signal from the transducer means for analysis thereof.

25. An apparatus as claimed in claim 24, wherein said processing means positions said product end gate substantially directly after said second time gate irrespective of said distance.

26. An apparatus as claimed in claim 23, 24 or 25, wherein said processing means controls said transducer means to inspect the first and second surfaces until said position signal reaches a first predetermined threshold, ceases inspection of said first surface and continues inspection of said second surface.

27. An apparatus as claimed in claim 26, wherein said first predetermined threshold corresponds to a distance at which substantially all of said first surface has been inspected.

28. An apparatus as claimed in claim 26 or 27, wherein, in use, said processing means overlays the product end gate over the first time gate so as to substantially discount and defect signals reflected from the first surface.

29. An apparatus as claimed in claim 26, 27, or 28 wherein, in use, said processing means ceases inspection of said second surface when said position signal reaches

a second predetermined threshold, smaller than said first predetermined threshold.

30. An apparatus as claimed in claim 29, wherein said second predetermined threshold corresponds to a distance at which substantially all of said second surface has been completed or as much as is possible taking into account a beam width of the ultrasonic waves emitted from the transducer means.

31. An apparatus as claimed in any of claims 24 to 30, wherein said transducer means is movable toward the end, and said processing means moves said first time gate, said second time gate and said product end gate toward said end relative to the time of transmission of said ultrasonic waves.

32. An apparatus as claimed in claim 31, wherein said transducer means is movable in indexed step increments.

33. An apparatus as claimed in any of claims 23 to 32, wherein, in use, said transducer means transmits ultrasonic waves longitudinally and transversely into said product.

34. An apparatus as claimed in any of claims 23 to 33, wherein, in use, said transducer means transmits ultrasonic waves obliquely into the product.

35. An apparatus as claimed any of claims 23 to 34, wherein said transducer means comprises a plurality of transducers and a single beam passage area in a body on which said transducers are mounted through which said ultrasonic waves can be transmitted and received.

36. An apparatus as claimed in any of claims 23 to 35, further comprising means for accommodating said product at a location at which the position of the transducer means with respect to said end is known, and means for providing a reference signal from which said distance can be determined.

37. An apparatus as claimed in any of claims 23 to 36,

wherein, in use, said transducer means are movable toward the end, the apparatus further comprising means for generating a proximity signal when the transducer means passes a predetermined location, and in response to the proximity signal said means for processing determine whether there is evidence of a man-made defect in the product at a predetermined range from the transducer means, the existence of said evidence establishing the position of the transducer means with respect to said end.

38. An apparatus as claimed in any of claims 16 to 27, wherein, in use, said transducer means are movable toward the end, the apparatus further comprising means for generating a first proximity signal when the transducer means passes a first predetermined location, and ceasing inspection of said first surface in response to said first proximity signal.

39. An apparatus as claimed in claim 38, the apparatus further comprising means for generating a second proximity signal when the transducer means passes a second predetermined location, and ceasing inspection of said second surface in response to said second proximity signal.

40. An apparatus as claimed in any of claims 23 to 39, further comprising sensor means on said transducer means for sensing said end.

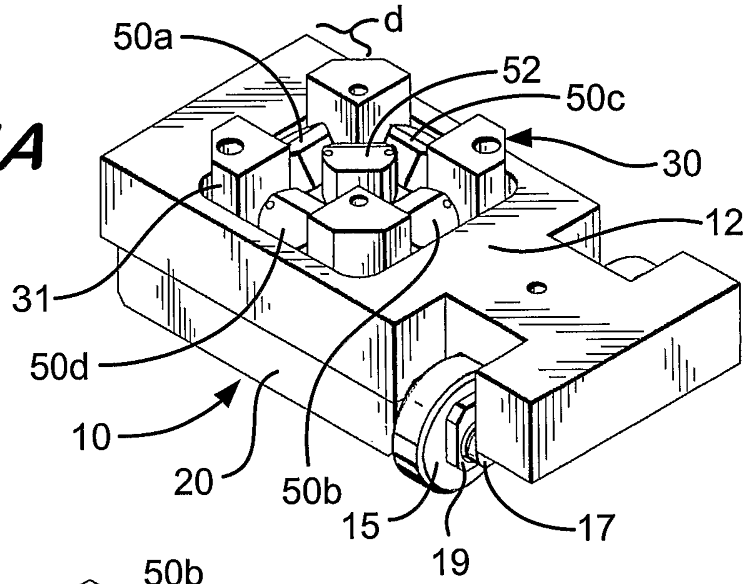
41. An apparatus as claimed in any of claims 23 to 40, further comprising proximity sensor means for sensing the proximity of said transducer means.

42. A product to be inspected by a method according to any of claims 1 to 22 or with an apparatus according to any of claims 23 to 41, said product having at least one man-made defect.

43. A body for mounting a plurality of ultrasonic transducers, which body comprises a plurality of

positions at which said plurality of transducers can be mounted respectively, and waveguide means that, in use, guide waves from each transducer through a single opening in the body to a product under inspection, and through which single opening waves reflected from the product pass and are guided back to the transducers by said waveguide means.

Fig.1A



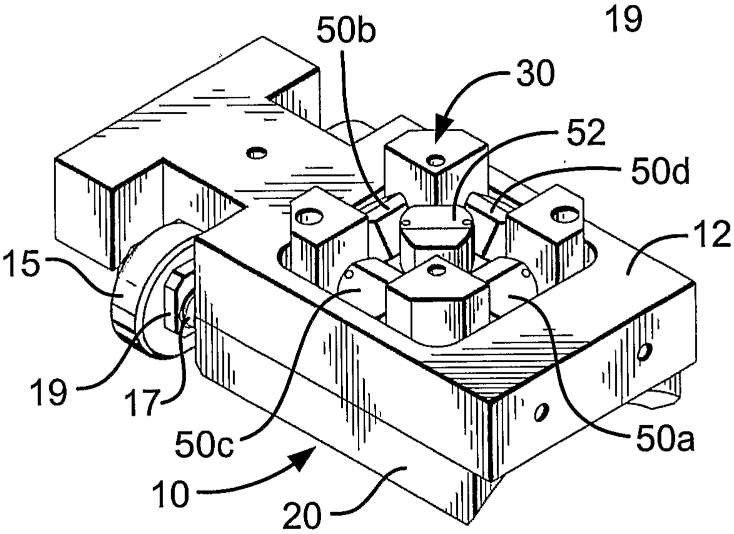
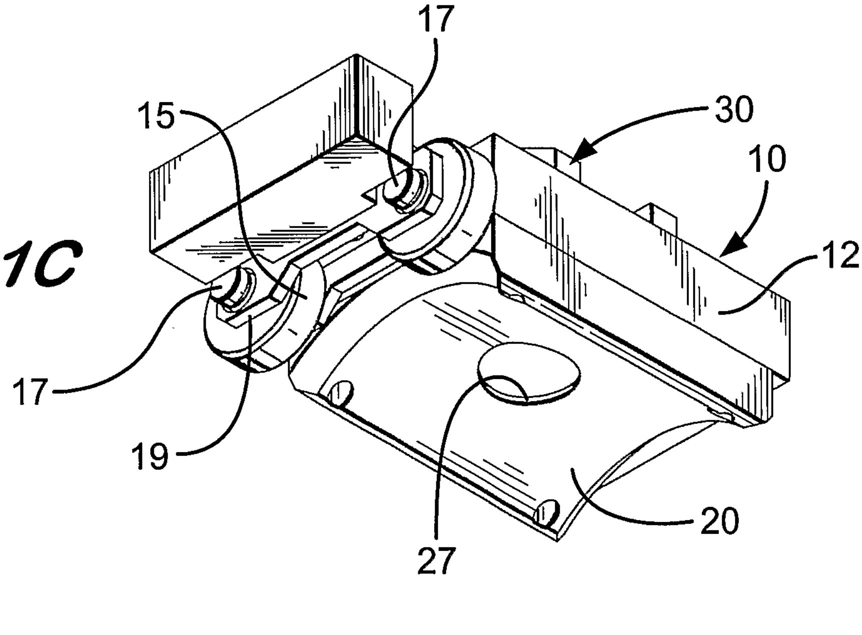


Fig.1B

Fig.1C



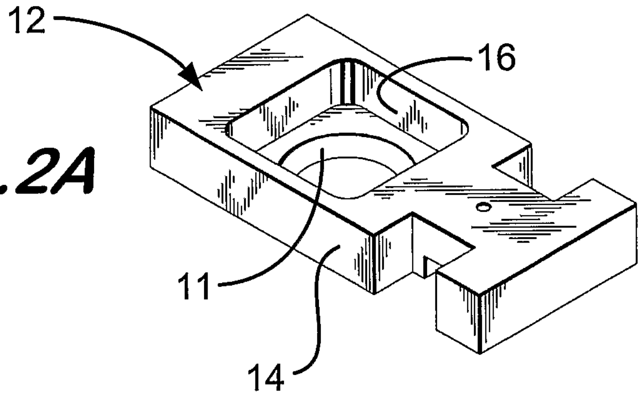


Fig.2A

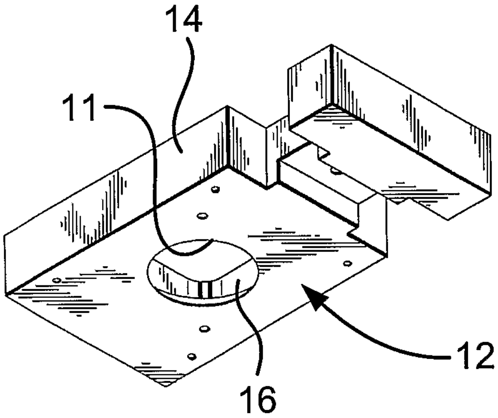


Fig.2B

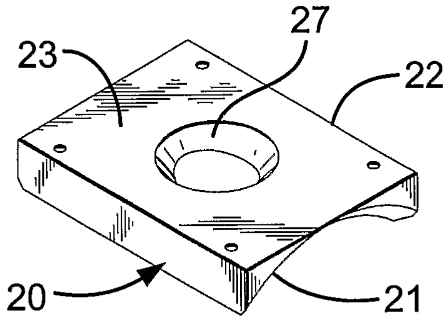


Fig.3A

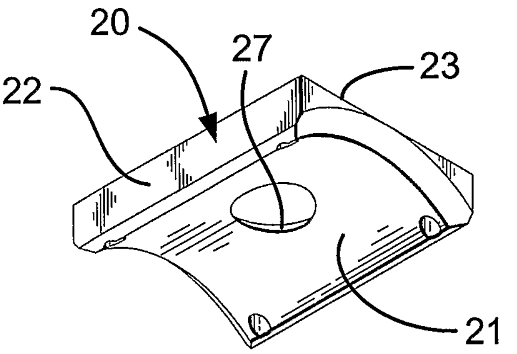
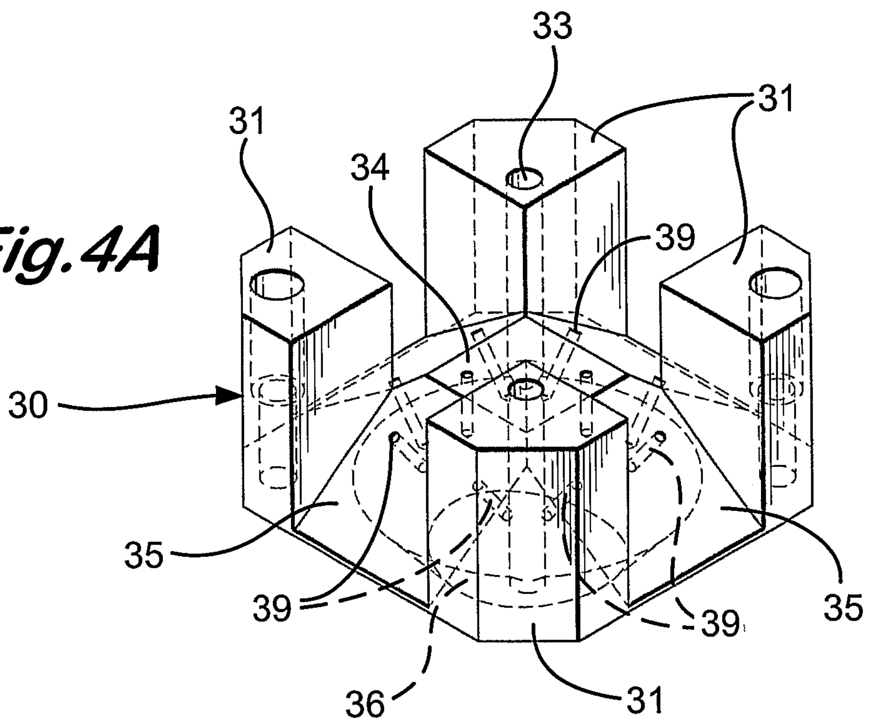


Fig.3B

Fig.4A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31
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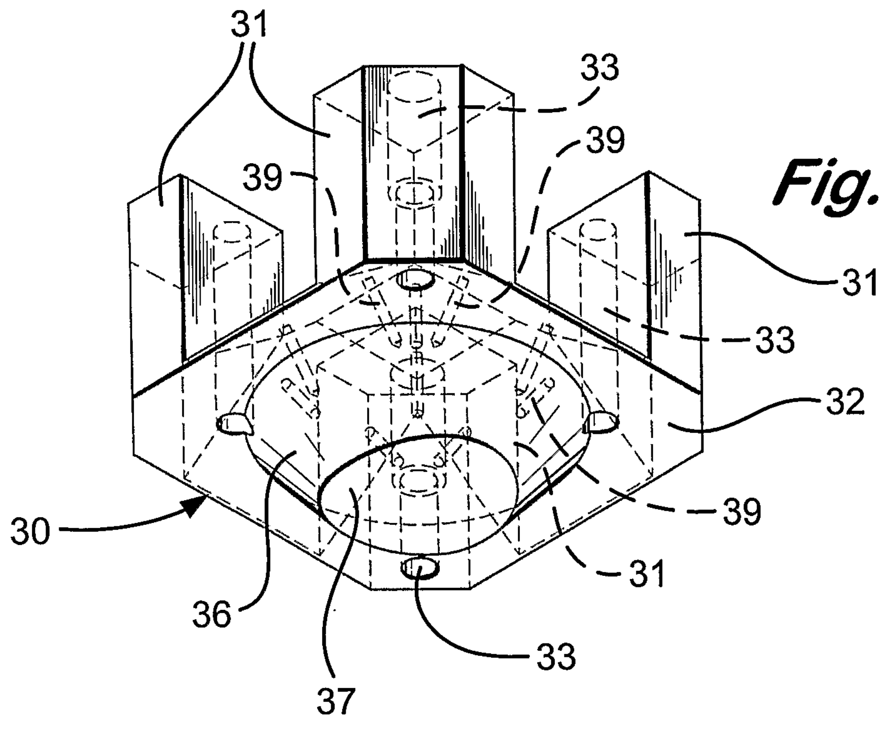
36
31

Fig.4B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33
37

Fig.5A

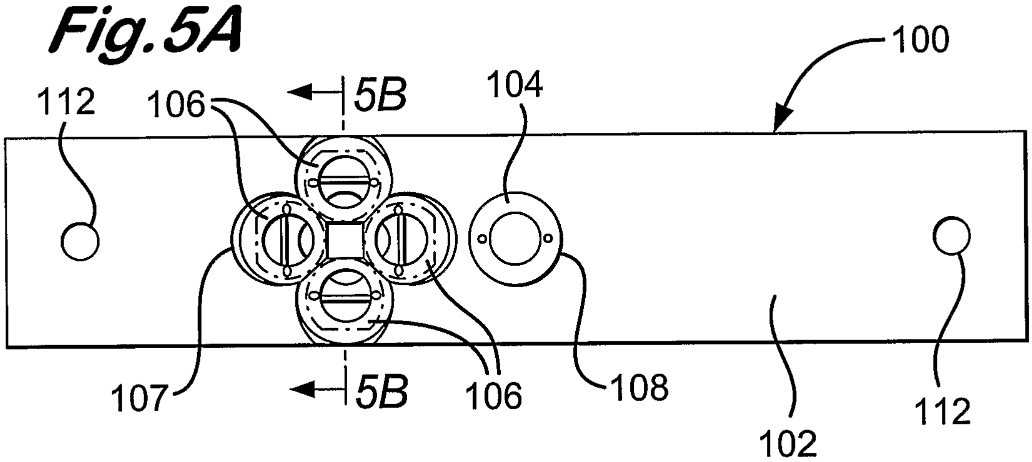


Fig.5B

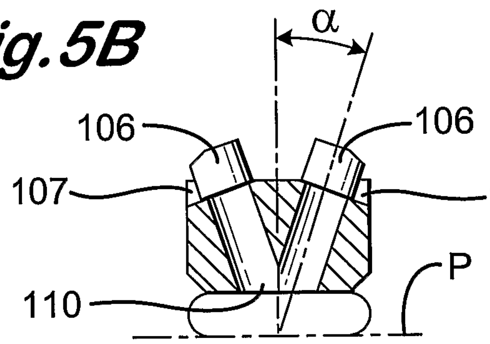


Fig.5C

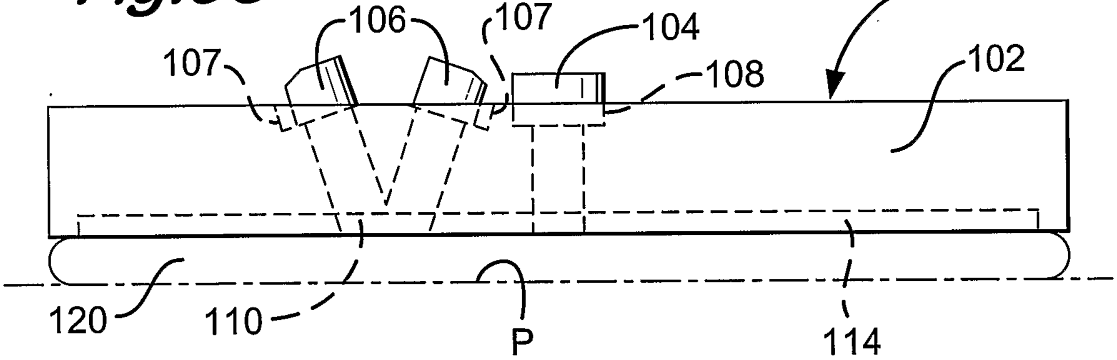


Fig.5D

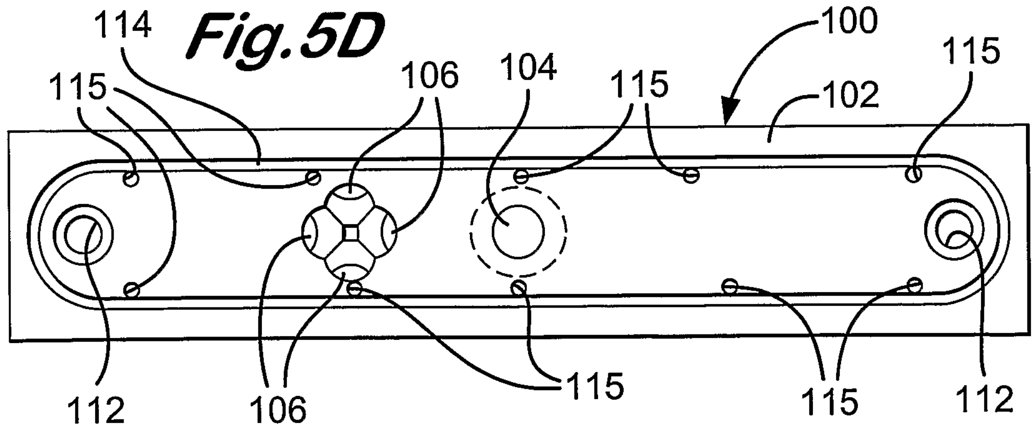


Fig.6A

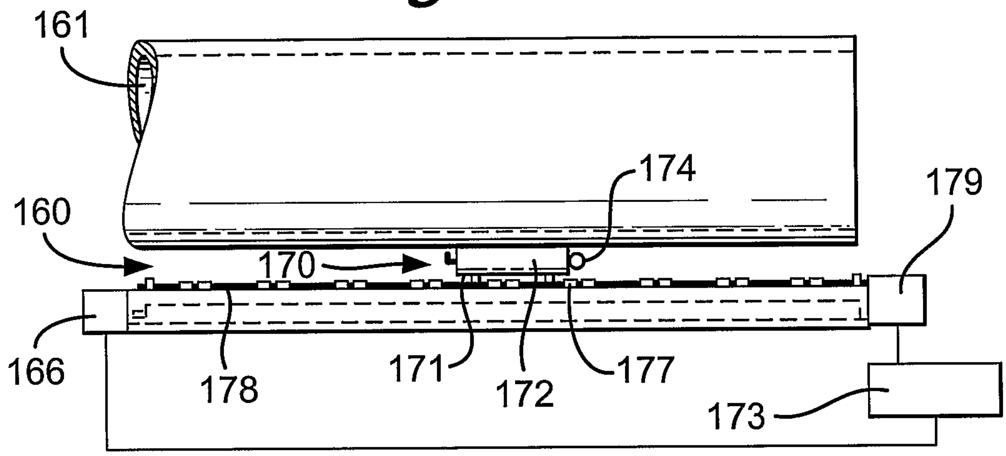


Fig.6B

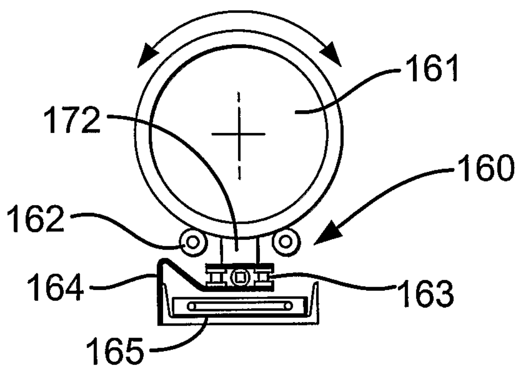


Fig.6D

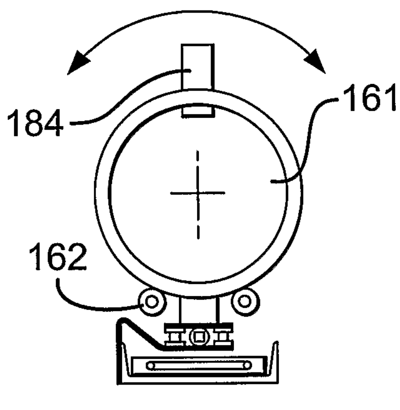
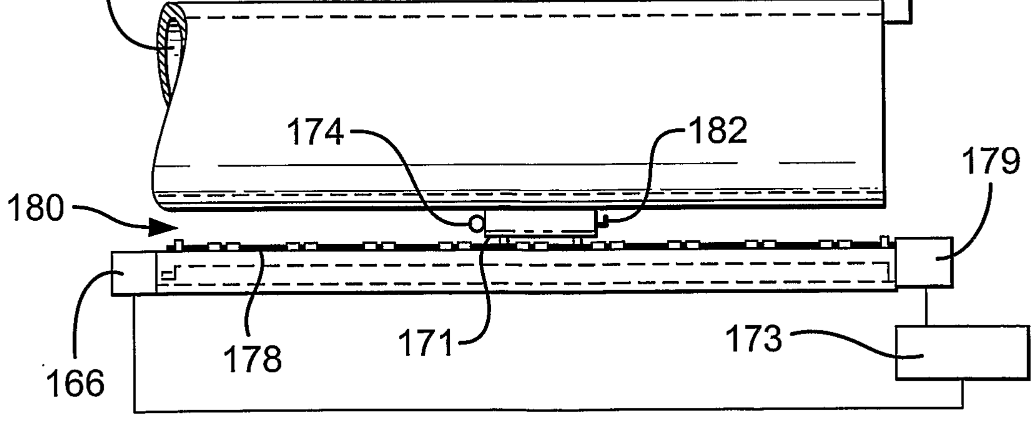
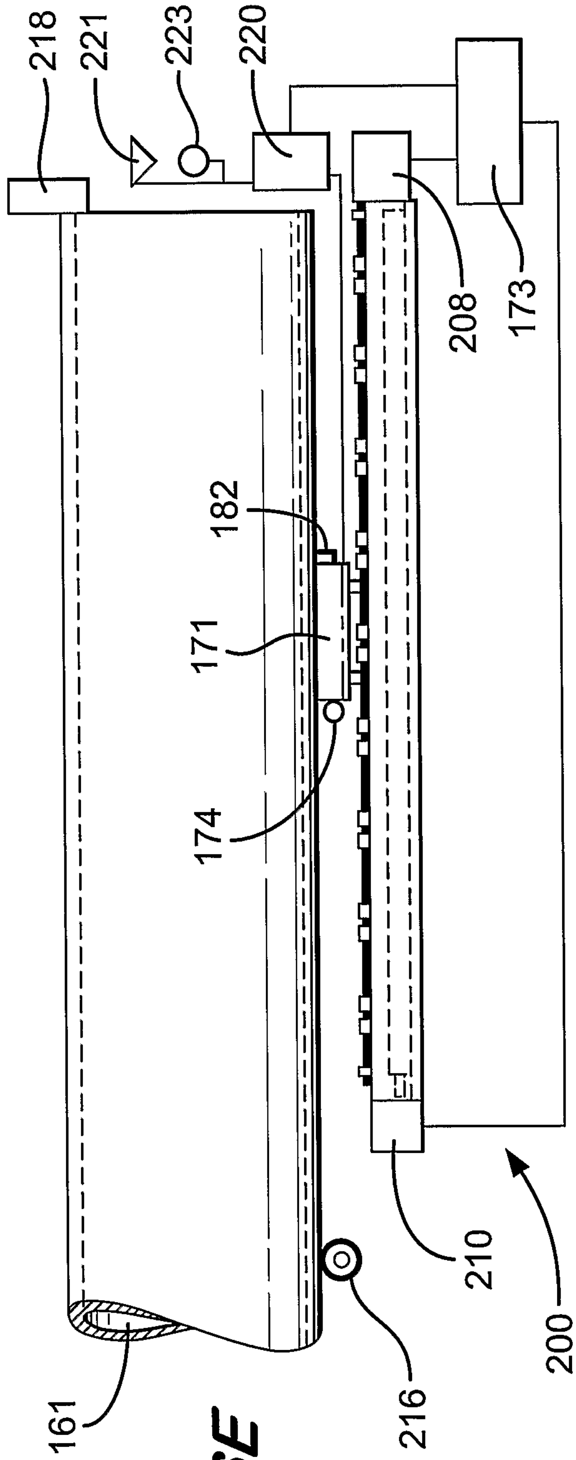


Fig.6C

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173
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174
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200
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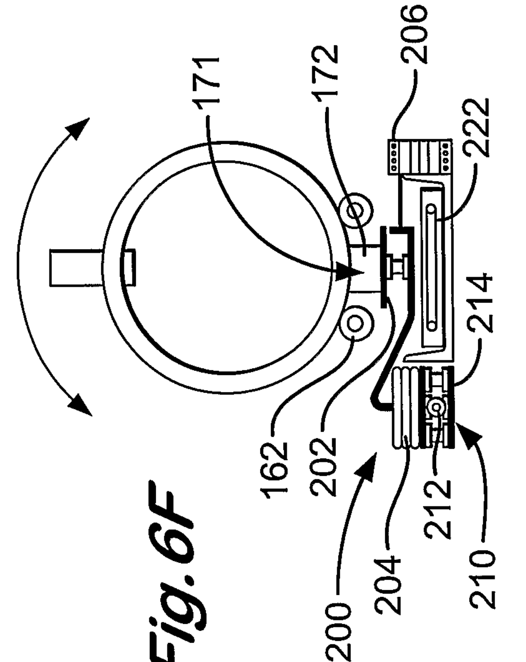
161

Fig.6E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210

Fig.6F

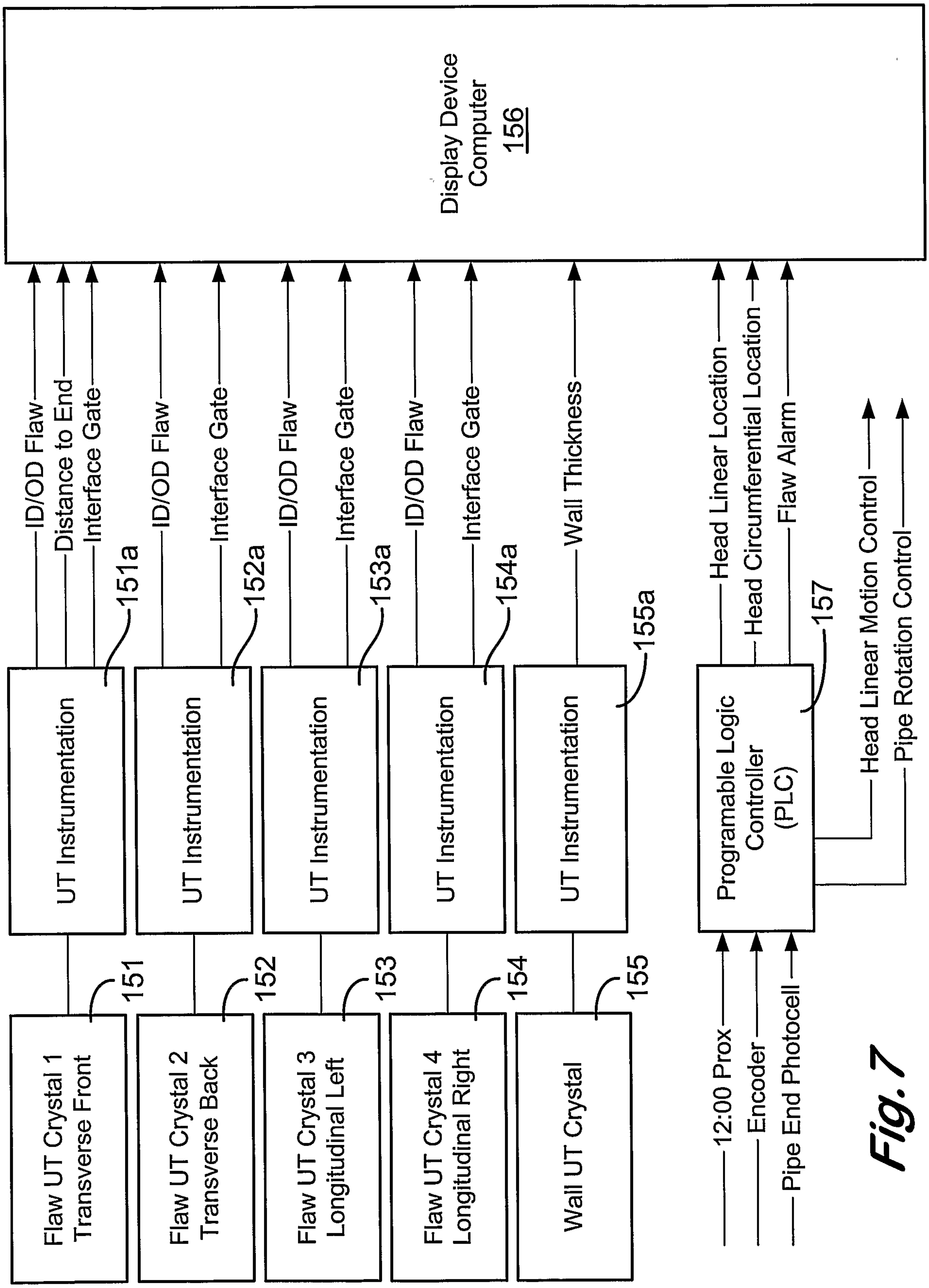

Display Device
Computer
156
ID/OD Flaw
Distance to End
Interface Gate
151a
ID/OD Flaw
Interface Gate
152a
ID/OD Flaw
Interface Gate
153a
ID/OD Flaw
Interface Gate
154a
Wall Thickness
155a
Head Linear Location
Head Circumferential Location
Flaw Alarm
157
UT Instrumentation
UT Instrumentation
UT Instrumentation
UT Instrumentation
UT Instrumentation
Programable Logic Controller (PLC)
Head Linear Motion Control
Pipe Rotation Control
151
152
153
154
155
Flaw UT Crystal 1 Transverse Front
Flaw UT Crystal 2 Transverse Back
Flaw UT Crystal 3 Longitudinal Left
Flaw UT Crystal 4 Longitudinal Right
Wall UT Crystal
12:00 Prox
Encoder
Pipe End Photocell

Fig. 7

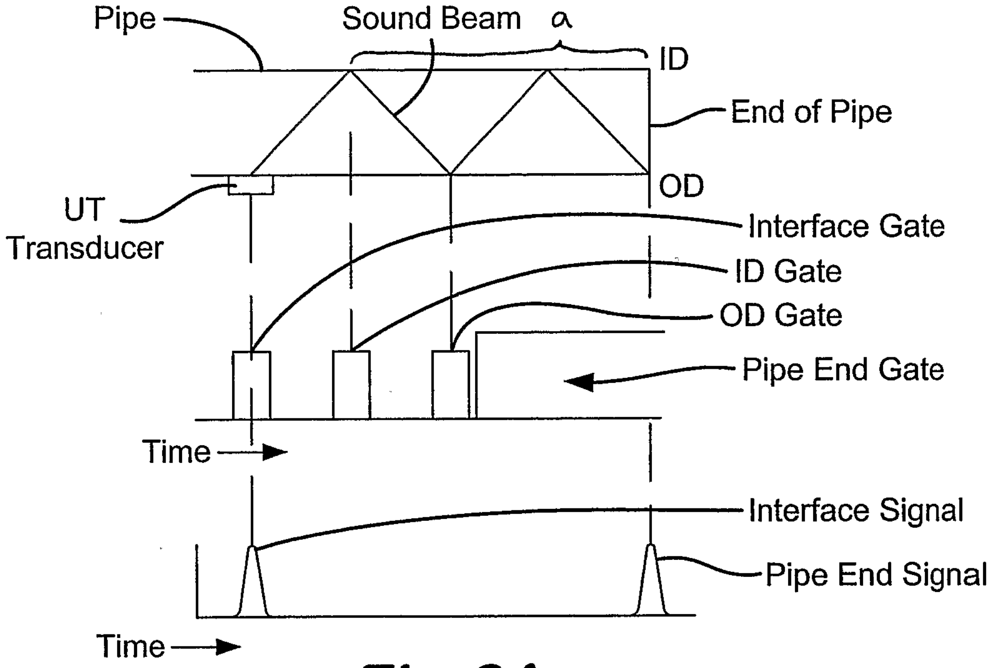

Pipe
Sound Beam
a
ID
End of Pipe
OD
UT
Transducer
Interface Gate
ID Gate
OD Gate
Pipe End Gate
Time
Interface Signal
Pipe End Signal
Time

Fig.8A

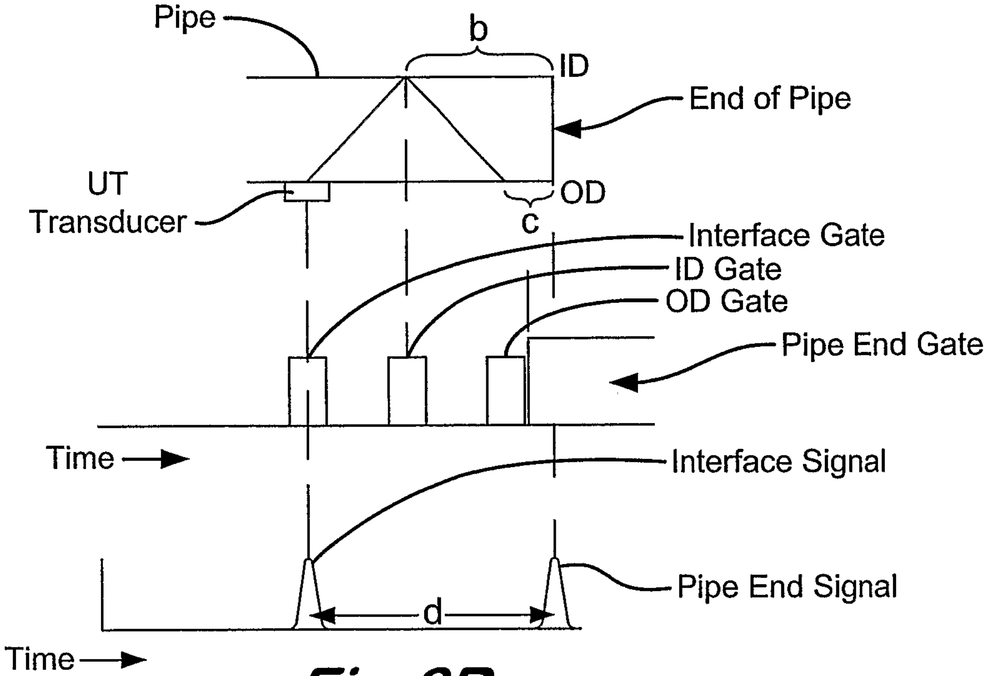

Pipe
b
ID
End of Pipe
UT
Transducer
OD
c
Interface Gate
ID Gate
OD Gate
Pipe End Gate
Time
Interface Signal
Pipe End Signal
d
Time

Fig.8B

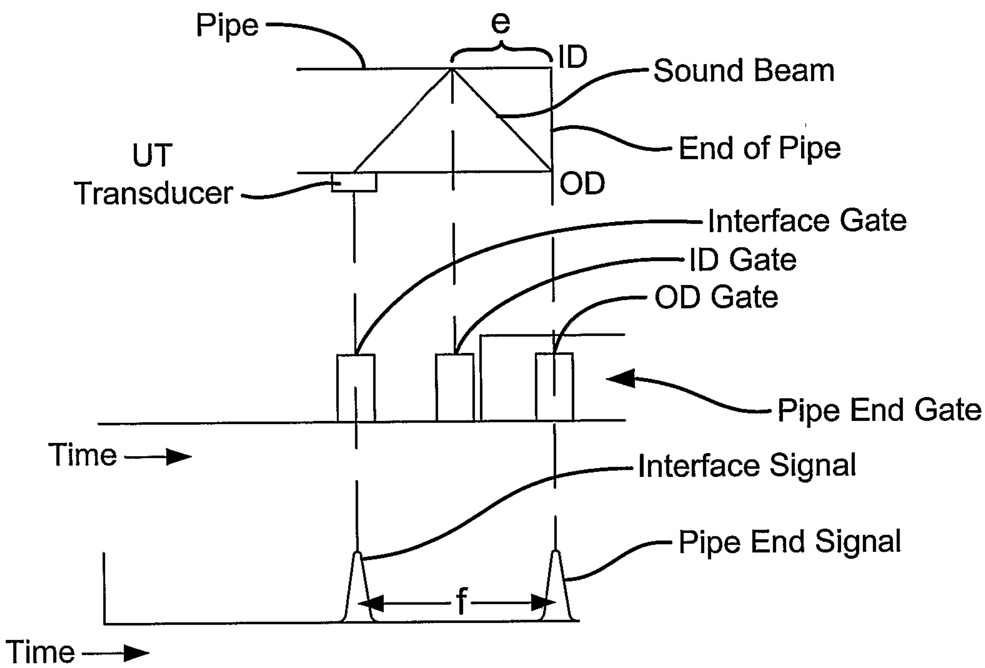

Pipe
e
ID
Sound Beam
End of Pipe
UT
Transducer
OD
Interface Gate
ID Gate
OD Gate
Pipe End Gate
Time
Interface Signal
Pipe End Signal
f
Time

Fig.8C

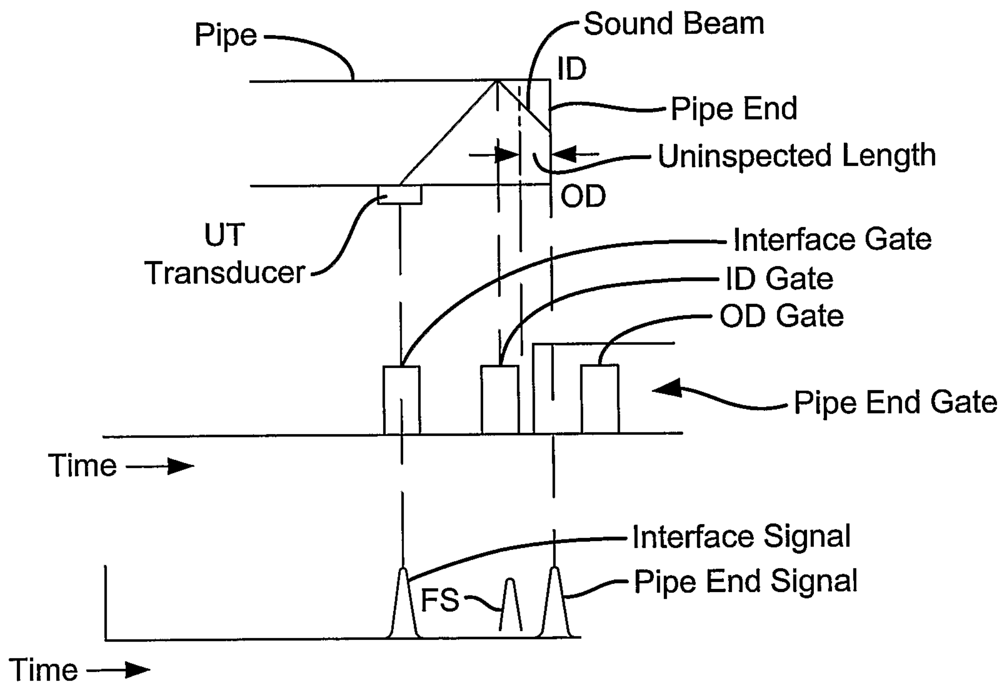

Sound Beam
Pipe
ID
Pipe End
Uninspected Length
OD
UT
Transducer
Interface Gate
ID Gate
OD Gate
Pipe End Gate
Time
Interface Signal
Pipe End Signal
FS
Time

Fig.8D

Fig.9A

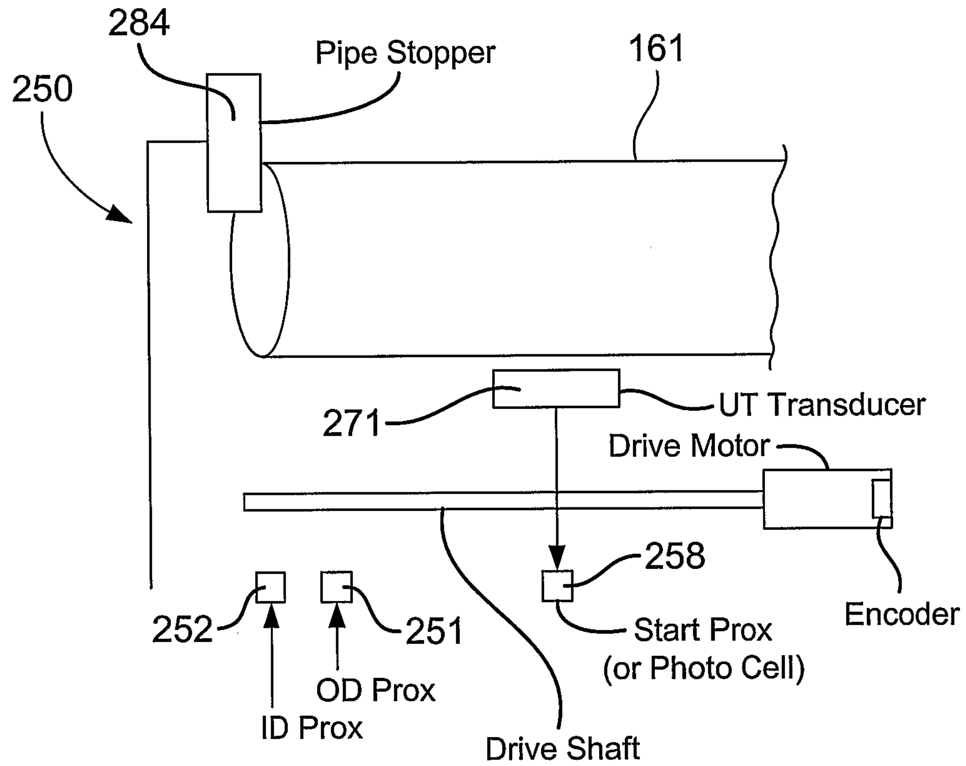

284
Pipe Stopper
161
250
271
UT Transducer
Drive Motor
258
Encoder
252
251
Start Prox
(or Photo Cell)
OD Prox
ID Prox
Drive Shaft

Fig.9B

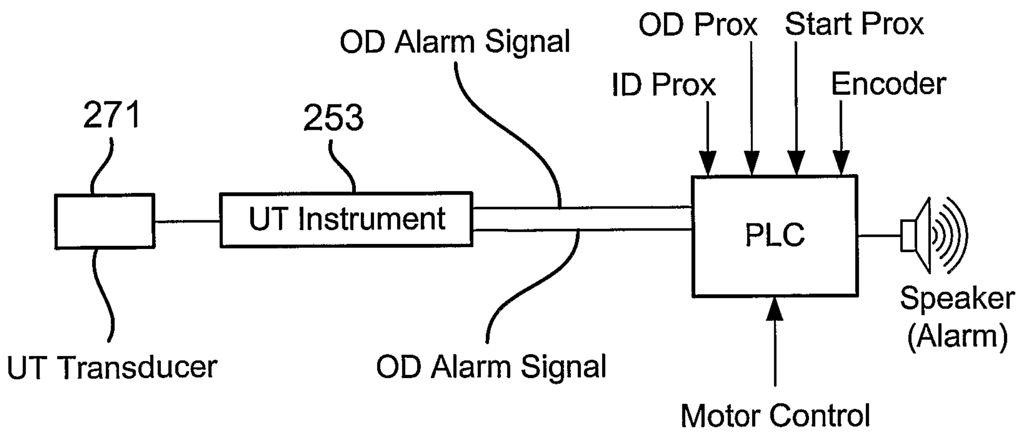

OD Alarm Signal
OD Prox
Start Prox
ID Prox
Encoder
271
253
UT Instrument
PLC
UT Transducer
OD Alarm Signal
Speaker
(Alarm)
Motor Control

Fig. 10A

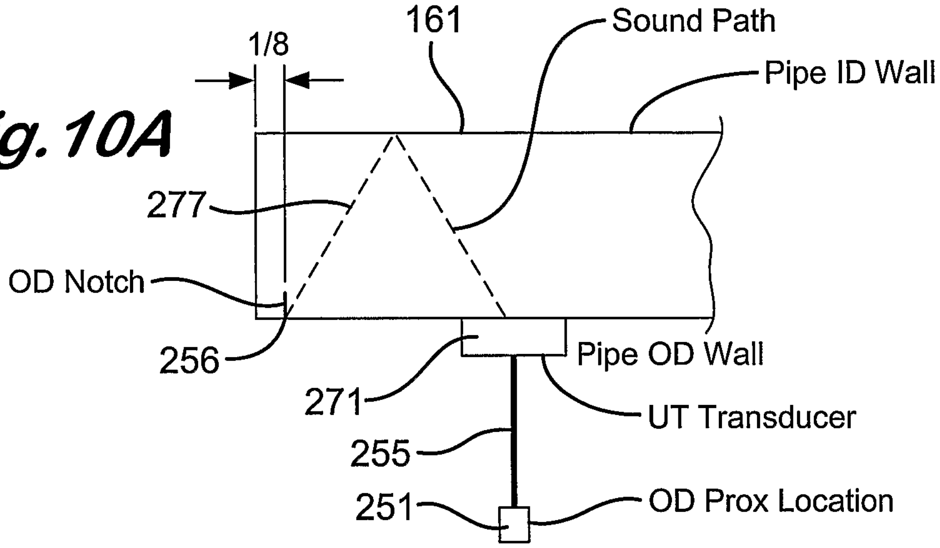


Fig. 10B

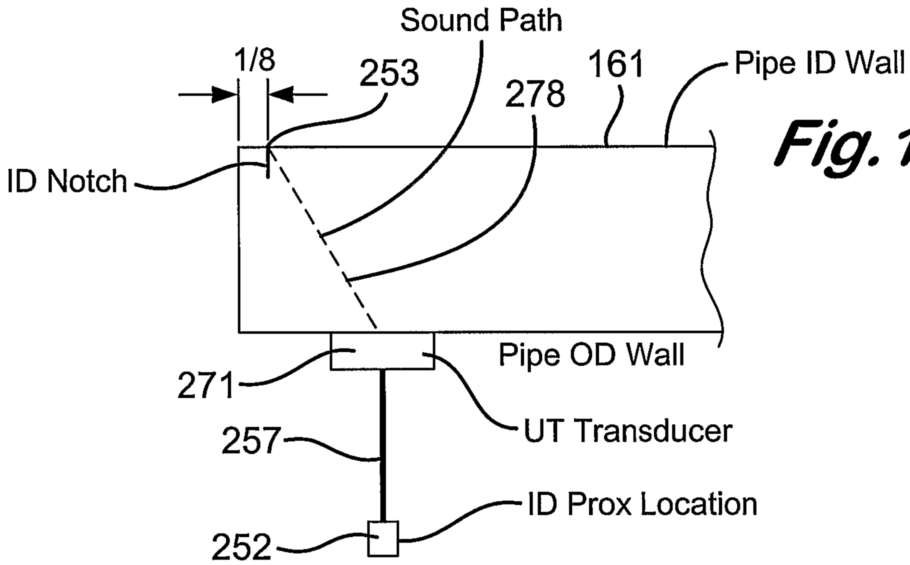
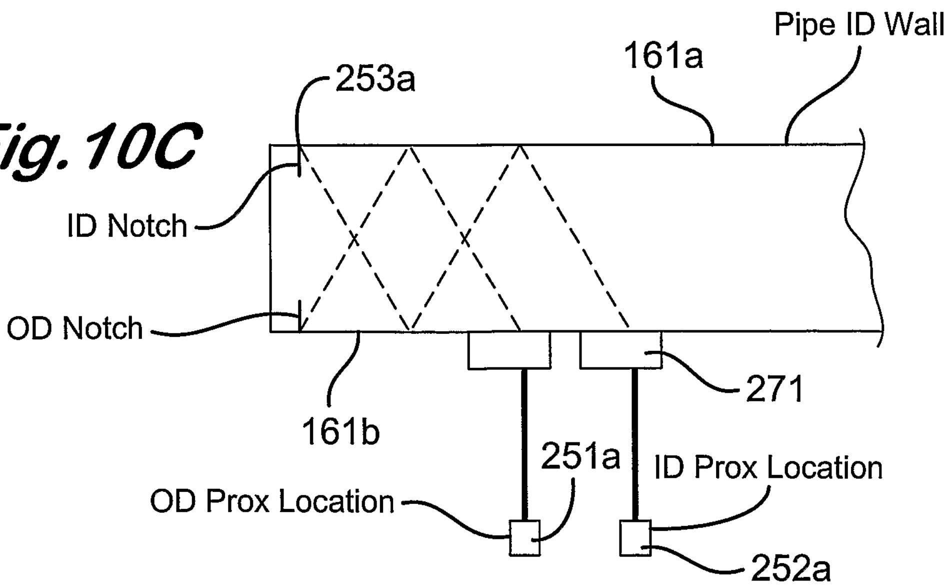


Fig. 10C



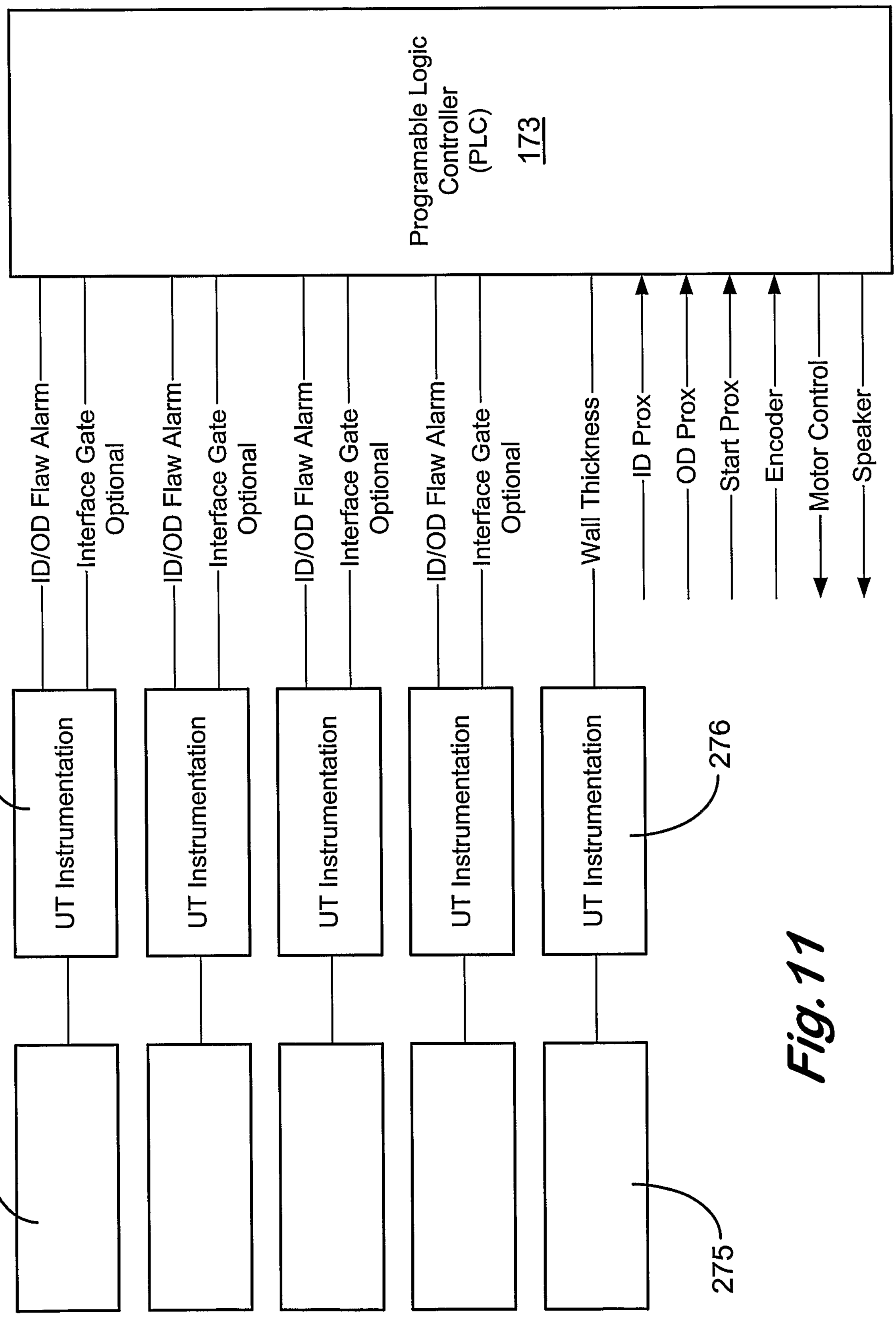

Programable Logic Controller (PLC)
173
ID/OD Flaw Alarm
Interface Gate Optional
ID/OD Flaw Alarm
Interface Gate Optional
ID/OD Flaw Alarm
Interface Gate Optional
ID/OD Flaw Alarm
Interface Gate Optional
Wall Thickness
ID Prox
OD Prox
Start Prox
Encoder
Motor Control
Speaker
UT Instrumentation
UT Instrumentation
UT Instrumentation
UT Instrumentation
UT Instrumentation
253
276
271
275

Fig. 11