

June 24, 1969

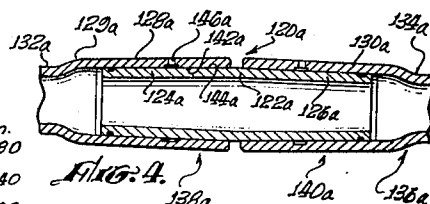
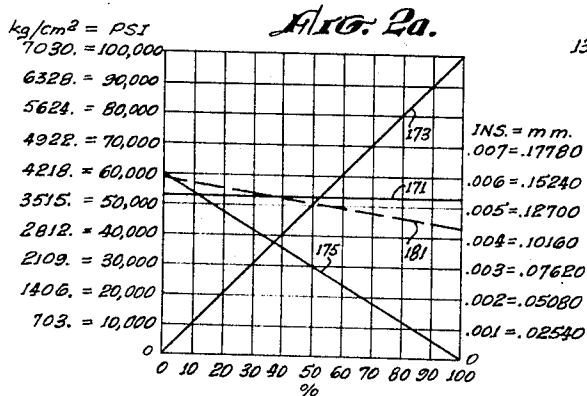
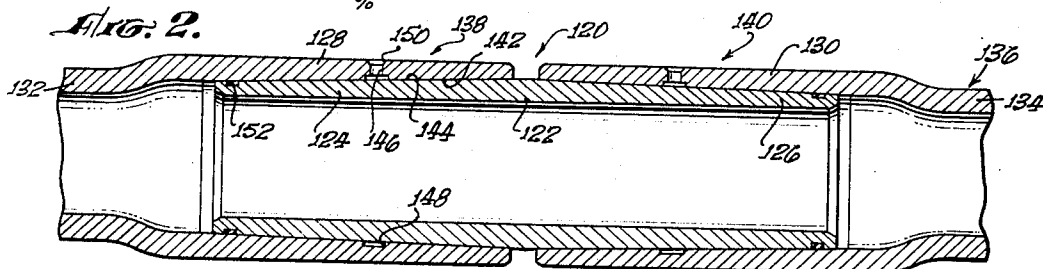
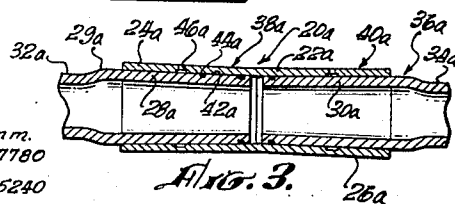
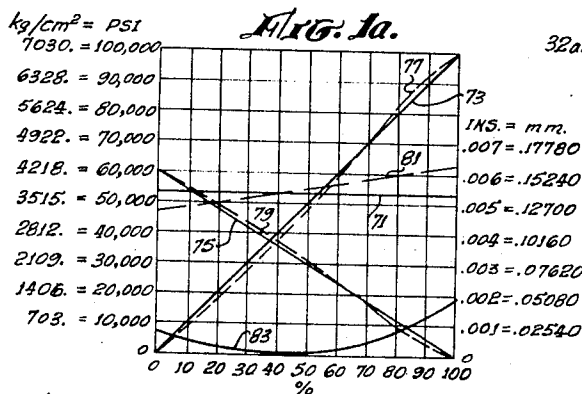
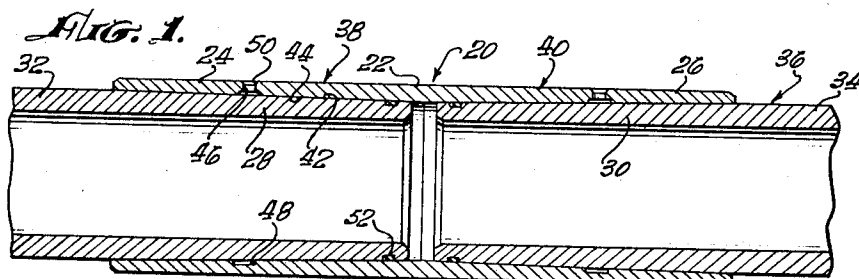
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3,451,119

METHOD OF AND APPARATUS FOR MAKING UP AND BREAKING
FRICTION-TYPE ROD AND TUBING JOINTS

Filed Nov. 22, 1963

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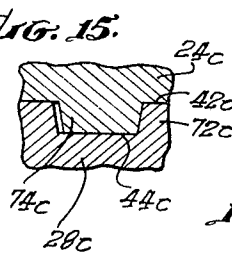
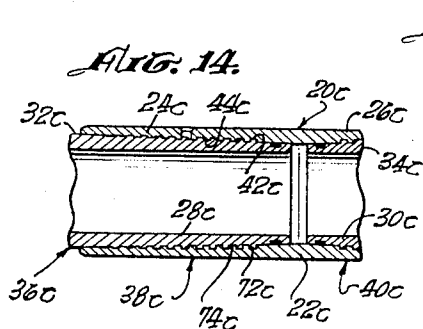
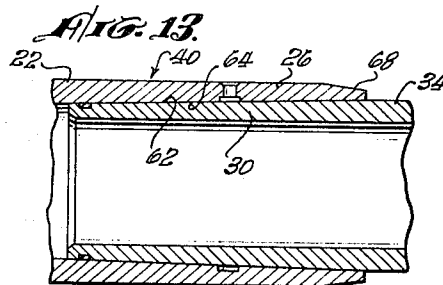
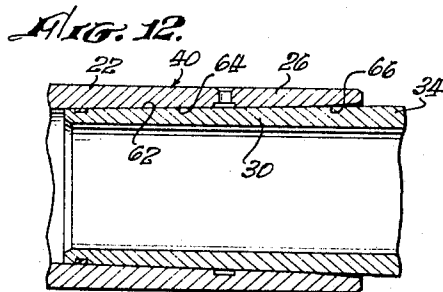
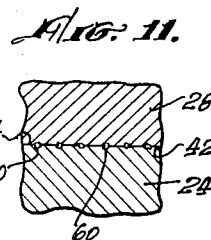
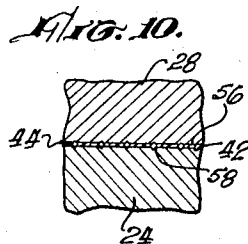
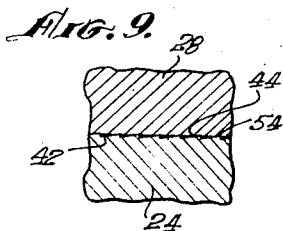
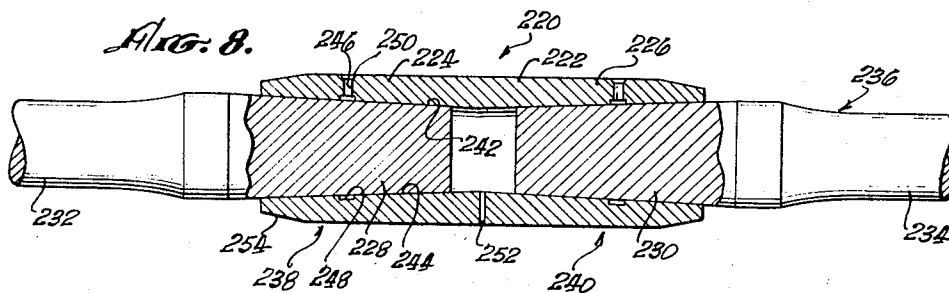
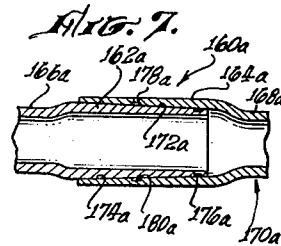
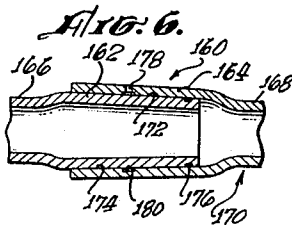
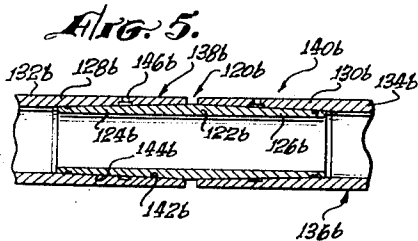
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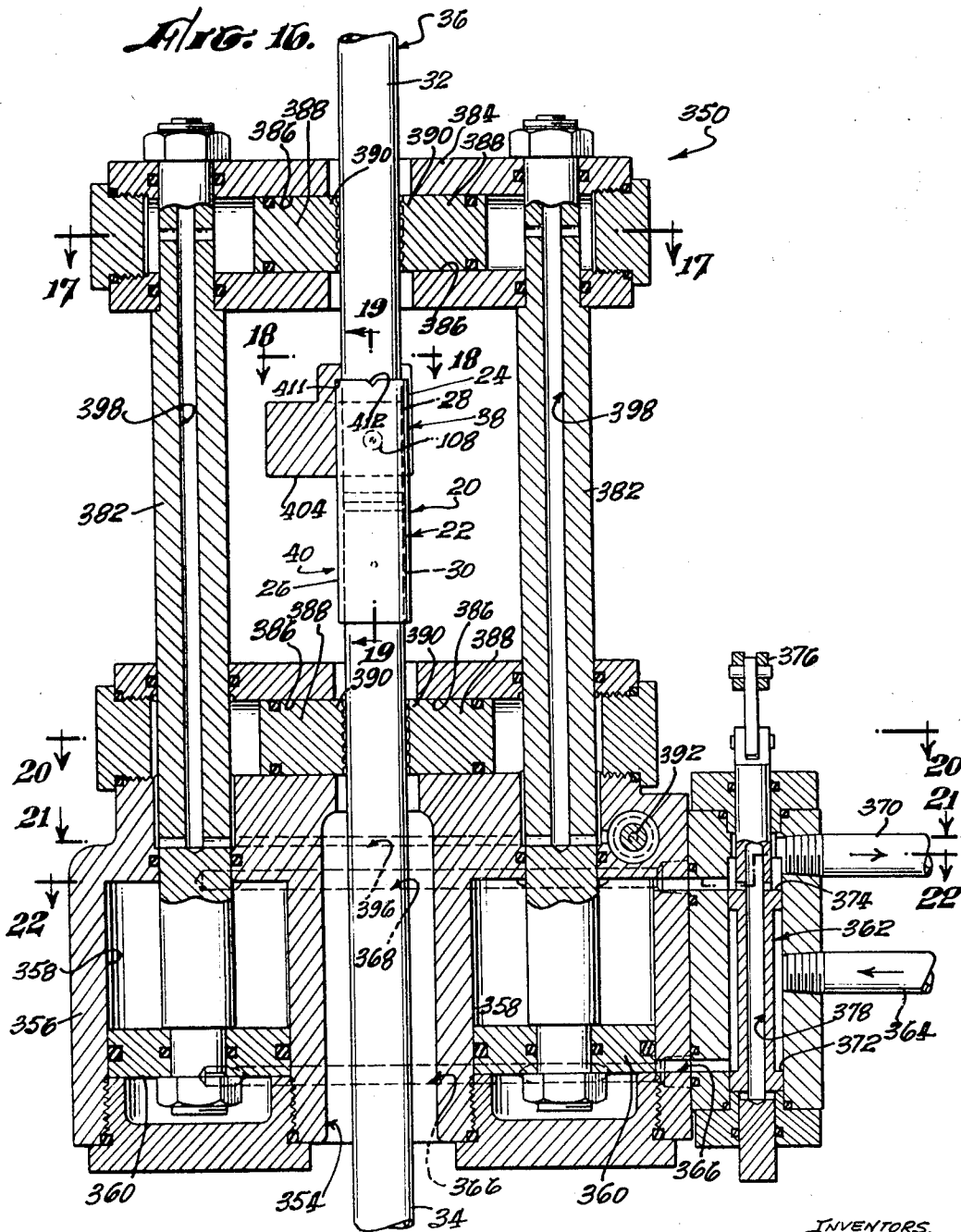
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Fig. 17.

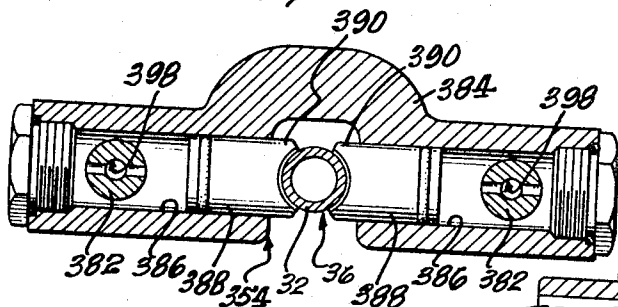


Fig. 18.

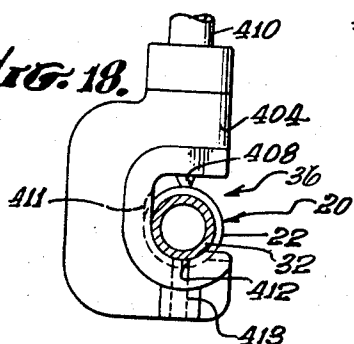


Fig. 20.

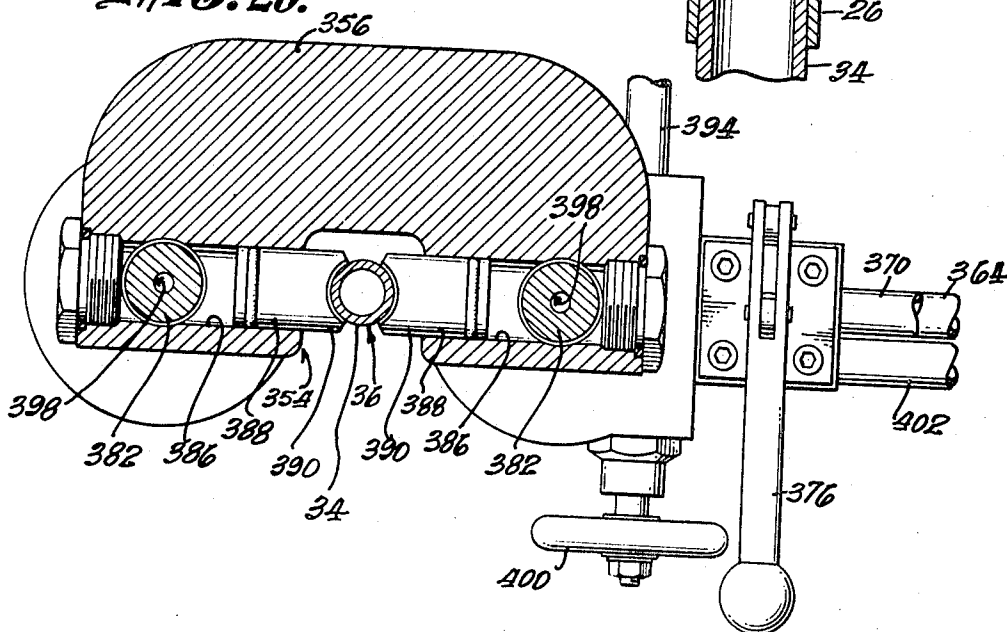
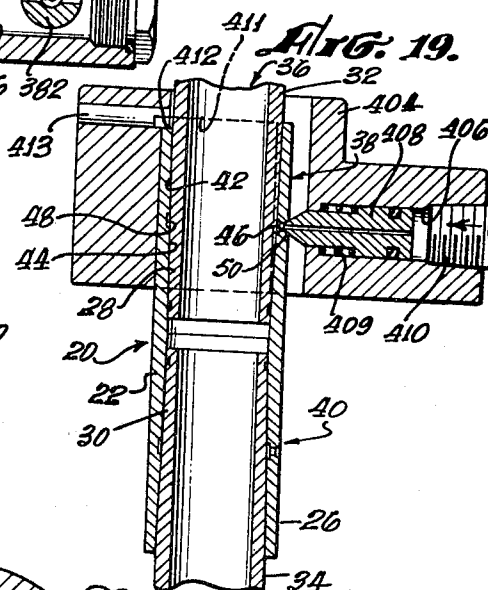


Fig. 19.



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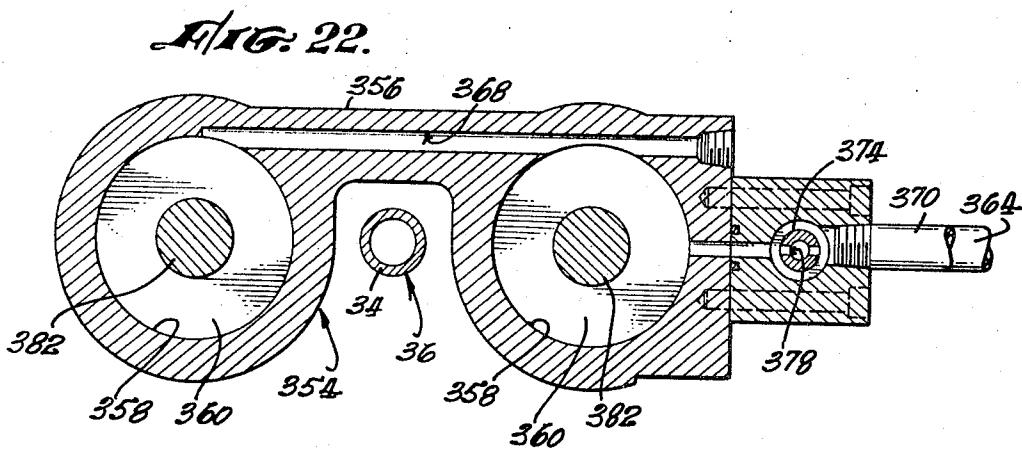
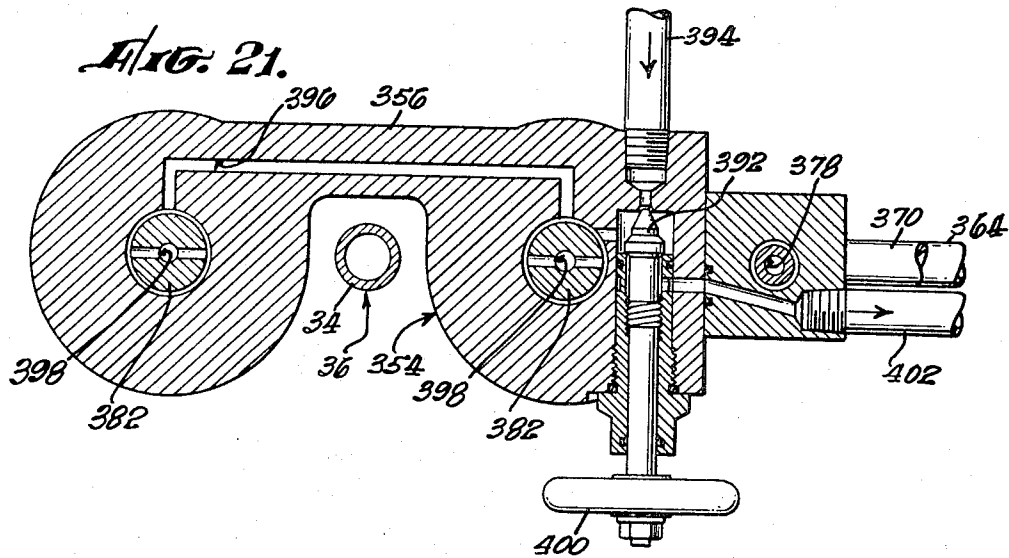
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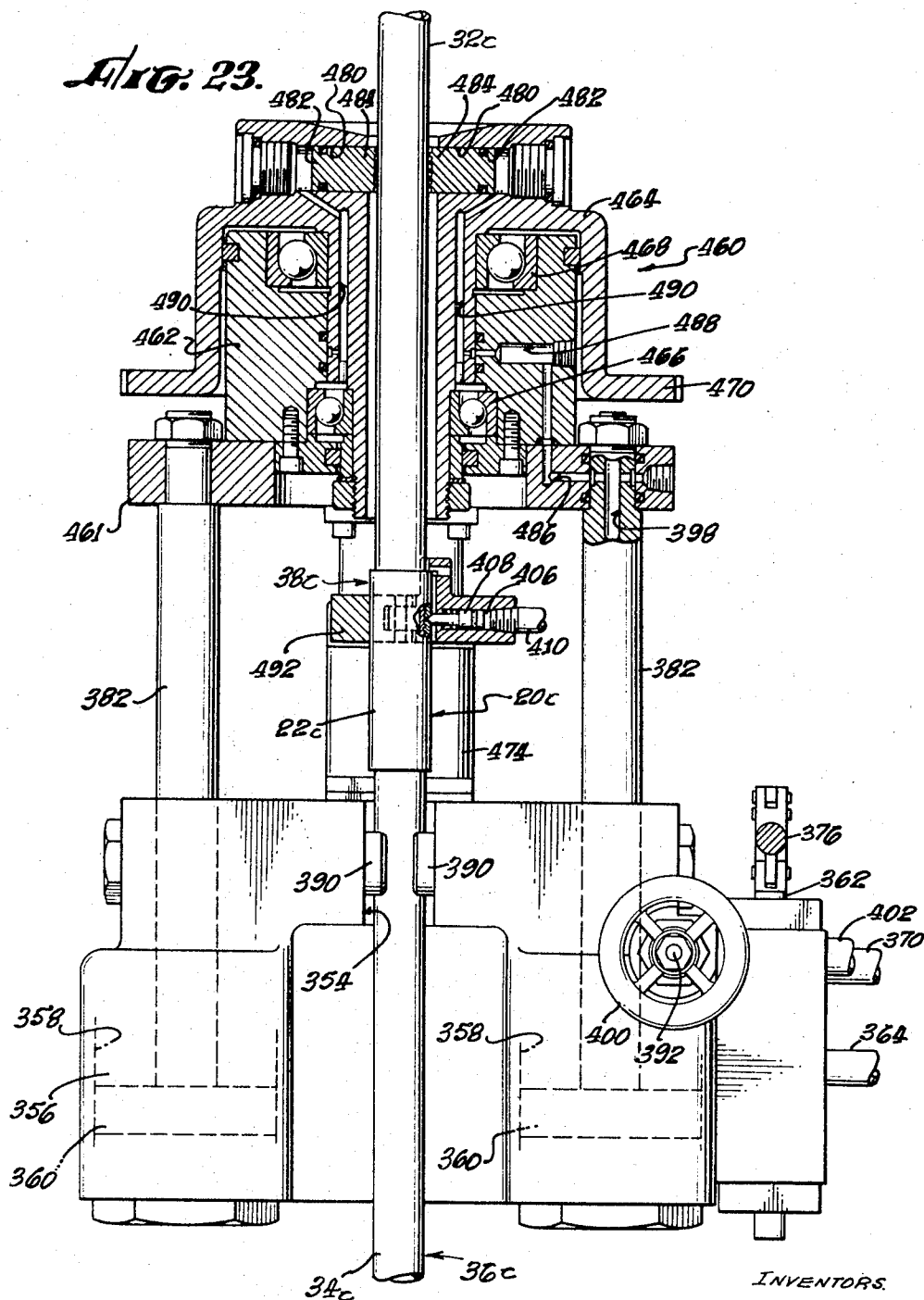
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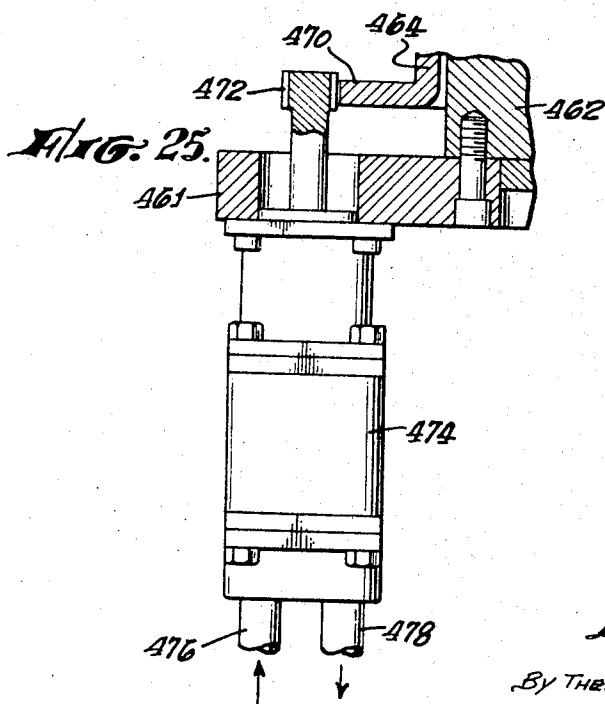
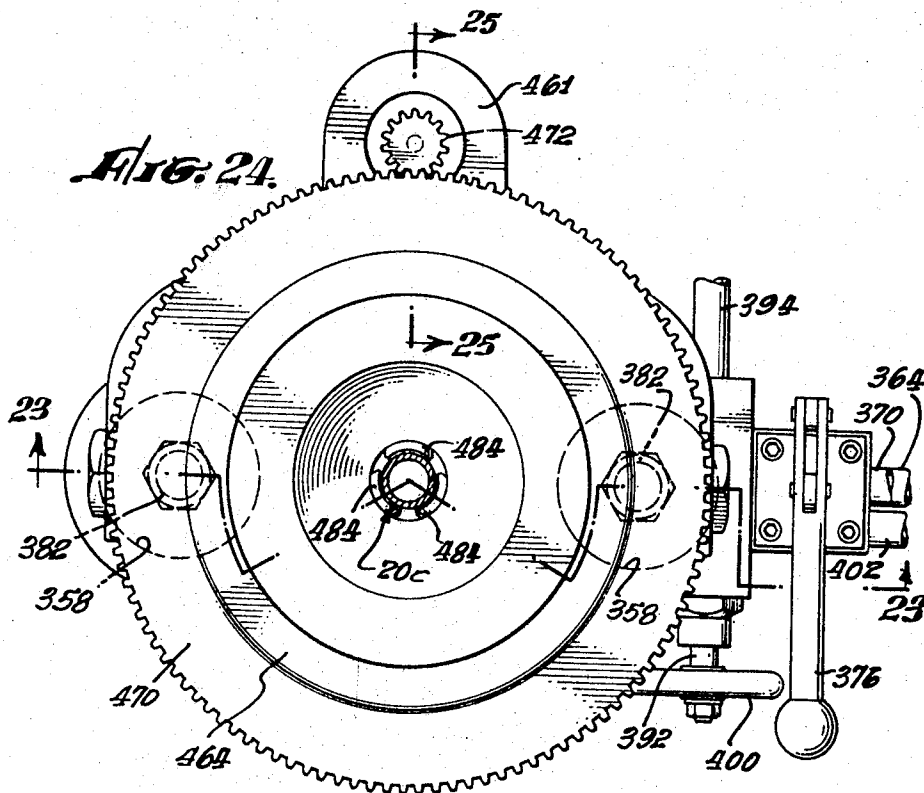
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METHOD OF AND APPARATUS FOR MAKING UP AND BREAKING FRICTION-TYPE ROD AND TUBING JOINTS

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Continuation-in-part of application Ser. No. 104,564, Apr. 21, 1961. This application Nov. 22, 1963, Ser. No. 325,707

Int. Cl. B23p 11/02; F16d 55/00

U.S. Cl. 29—446

12 Claims

ABSTRACT OF THE DISCLOSURE

A method of and apparatus for making up and/or breaking tapered friction-type rod or tubing joints. Each joint includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces pressurally interengageable along an interface therebetween, one of these members being an end portion of a tubing or rod. The outer tubular member of the joint has a port therethrough opening on its inner tapered surface approximately at the axial midpoint thereof. The method and apparatus provide for injecting fluid through the port in the outer tubular member into a central region of the interface between the tapered surfaces under high pressure sufficient to stress the materials of the inner and outer members in the central region to values close to, but less than, their respective yield points, whereby to expand the outer member and contract the inner member in the central region to permit relative axial movement of the members resulting in insertion of the inner member into the outer tubular member. The axial length of the tapered surface is in pressural inter-engagement with each other is so related to the engagement pressure between the surfaces and the effective coefficient of friction therebetween as to produce a frictional resistance to relative bodily displacement of the surfaces sufficiently high to develop a joint strength at least nearly equal to the yield strength of the tubings or rods interconnected by the joint. The apparatus includes a system of relatively movable jaws for inserting the inner member into the outer tubular member while an injection means engageable with the outer tubular member around the port therein injects a fluid through the port into the central region of the interface between the tapered surfaces under the desired high pressure mentioned.

The present application is a continuation-in-part of our copending application Ser. No. 104,564, filed Apr. 21, 1961, now Patent No. 3,114,566, granted Dec. 17, 1963.

The present invention relates to a method of and apparatus for making up (and/or breaking) friction-type joints for interconnecting such elongated elements as tubings or rods, usually in end-to-end, aligned relation, to form tubing or rod strings capable of withstanding high axial and/or torsion loads, and/or, in the case of tubing strings, high internal pressures. Various high-strength, friction-type tubing and rod joints which may be made up and/or broken with the method and apparatus of the invention will also be disclosed.

Tubing or rod strings incorporating such friction-type

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joints may include any number of elongated elements oriented in any direction. One important use of such a rod or tubing string is in a well with the string oriented vertically and subjected to high axial tension loads may be due to its weight. Additionally, such high axial tension loads may be due in part to a high internal pressure in the case of a tubing string, or a high pumping load in the case of a rod string. Alternatively, or additionally, the string may be subjected to high torsion loads, as in the case of a drill string.

The term "tubing" is used herein to include tubes or pipes of any lengths and wall thicknesses. Tubings may be classed as thin walled or thick walled relative to their outer diameters. Such classes of tubings differ in that, in a thin-walled tubing, any hoop stresses developed therein are substantially uniform throughout the thickness of the wall, whereas, in a thick-walled tubing, there is a distinct hoop stress gradient throughout the thickness of the wall. Tubings commonly used in oil wells may be regarded as falling into the thin-walled class, examples being tubings or pipes used in producing oil, drill pipe, casing, liners, and the like.

The term "rod" is used herein to cover solid, i.e., nontubular, elongated elements. Rod strings are widely used in the oil industry for transmitting power from the surface to bottom hole pumps in oil wells, the rods commonly being referred to as "sucker rods."

Friction-type joints with which the method and apparatus of the invention may be used rely for axial and torsional strength predominantly or exclusively on frictional resistance to relative bodily displacement of axially tapered surfaces of an inner member and an outer, tubular member fitted over the inner member, the tapered surfaces being frictionally interengaged, usually in direct physical contact, with a high engagement or contact pressure therebetween along an interface which is substantially continuous and tapers substantially uniformly throughout the axial length of frictional interengagement between said tapered surfaces, and which has a small included angle. Both such members may be adjacent ends or end portions of adjoining elongated elements, or one may be an end or end portion of an elongated element and the other an end or end portion of a coupling. Normally, the coupling will have oppositely tapered end portions for pressural interengagement with complementarily tapered surfaces of adjacent ends of two elongated elements to be interconnected by the coupling. In most instances, the coupling is tubular and may be either internal or external with respect to the tubing or rod ends to be interconnected thereby.

It is important that the strength of such a friction-type joint against relative bodily displacement of its tapered surfaces should be at least nearly equal to the yield strength of the elongated elements it interconnects. While stresses in rod or tubing strings used in oil wells are within the elastic limit of the rods or tubings during normal use, it is important that none of the joints fail if higher stresses are transiently developed under unusual conditions. Under such circumstances, it is important that axial tension loads, for example, up to the yield strength, or even the ultimate strength, of the rods or tubings be applicable to the rod or tubing strings without failure of the joints thereof.

All conventional rod or tubing joints now in use are of the threaded variety and costly unsetting and heat

treatment is required if the joint strength is to equal or exceed the tensile strength of the rod or tubing. In addition, threaded joints are necessarily bulky and occupy valuable space in the well. For example, it is often necessary to run two or more tubing strings side by side in a well casing and the size of conventional threaded joints limits the number of tubing strings that can be placed in the casing, or requires an increase in the size of the casing. It is a feature of the present friction-type joint that rods or tubings can be adequately connected in a rod or tubing string thereby in much less space than threaded joints. As compared with conventional practice, it is usually possible to employ well casings two full sizes smaller to contain an array of two or more parallel tubing strings, resulting in substantial savings in drilling and casing costs. Conversely, it becomes possible to use more or larger tubing strings in any existing casing or well. Generally similar considerations are applicable to rod strings using such a friction-type joint.

The strength of the present friction-type joint depends primarily on three factors, viz, the actual length of the interface throughout which the tapered surfaces are in pressural engagement, the effective coefficient of friction between the tapered surfaces, and the engagement pressure therebetween. The taper angle should be relatively small, but can vary throughout a relatively wide range as hereinafter discussed. It is desirable to design the joint to have a relatively high effective coefficient of friction and a very high engagement pressure between the tapered surfaces so that the length of the tapered surfaces in pressural interengagement can be relatively small. The foregoing factors can be so related as to produce a joint strength that is at least substantially equal to the yield strength of the rods or tubings interconnected by the joint. Ideally, the joint strength is equal to or exceeds the ultimate strength of the rods or tubings so that failure will occur in one of the rods or tubings, and not in the joint. It is surprising that a friction-type joint of such axial strength can be produced, but many tests have shown these results to be possible.

The desired high engagement pressure between the tapered surfaces of the inner and outer members of the friction-type joint is the result of a high hoop tension stress in the outer member and an opposing high compression stress in the inner member. To achieve maximum joint strength, these stresses approximate, but are slightly below, the yield strengths of the materials of the two members.

The high hoop tension stress in the outer member establishes therein an initial axial compression stress which, according to Poisson's ratio for steel, is approximately equal to 0.3 times the hoop tension stress. Such an initial axial compression tends to reduce the axial length of the outer member and tends to increase its taper angle to a related extent. Likewise, the opposing high compression stress in the inner member establishes therein an initial axial tension equal to about 0.3 times the stress in question. This similarly tends to lengthen the inner member and tends to decrease its taper angle. However, it has been found that the actual taper-angle changes are insignificant and do not affect the joint strength significantly.

Still another factor is that in applying an axial make up force to the members in making up the joint, the inner member may be subjected to an axial compressive stress tending to increase its diameter. Upon relaxation of the make up force, the diameter of the inner member tends to decrease to its original value, which would appear to tend to weaken the joint by reducing the engagement pressure. However, this effect has been found to be insignificant.

An external axial load applied to one of the members of the joint is transferred progressively to the other along the length of the interface throughout which the two tapered surfaces are pressurally interengaged. An axial

tensile stress due to an axial tension load is additive with respect to the initial axial tension stress in the inner member. Likewise, the axial tension stress due to such an axial load reduces the initial axial compression stress in the outer member to the point of changing it to a net axial tension stress along most of the length of the interface.

The engagement pressure between the tapered surfaces induced by the hoop tension and compression stresses in the outer and inner members changes upon application of such an axial load to one of the members. If it is assumed that initially the engagement pressure or interference fit between the surfaces was uniform along the interface, application of such an axial load will increase the contact pressure or interference fit near one end of the interface and decrease same near the other end thereof, only an intermediate portion of the interface being free of such effects. Likewise, application of such an axial load has been found to cause relative axial movement between the engaged tapered surfaces at positions near the ends of the interface.

It thus becomes apparent that any analysis of the stresses in the joint under initial and loaded conditions becomes extremely complex. Many of the factors noted above as concerns initial stress and change in stress upon axial loading might seem to indicate that no friction-type joint could be designed that would not pull apart at loads equal to the nominal yield strength or the nominal ultimate strength of the rods or tubings. Tests have shown, however, that a friction-type joint can be designed to meet these conditions without failure. It has been found that the change in axial stress in the members due to axial loading, change in engagement pressure or interference fit between the tapered surfaces upon such loading, and the relative movement between such surfaces upon such loading, are not such as to prevent the design of a friction-type joint having a strength greater than the yield or even the ultimate strength of the rods or tubings.

The friction-type joint is preferably so constructed that the outer tubular member will grip the inner member tighter upon the application of an axial tension load. The materials and dimensions of the inner and outer members may be so selected and related that at least a portion of the outer member contracts relative to the inner member upon application of an axial tension load to thereby increase the engagement pressure between the tapered surfaces adjacent such portion. This effect may be enhanced very considerably by utilizing for the inner member a material having an appreciably higher modulus of elasticity than the material of the outer member.

The tapered surfaces of the inner and outer members may be in direct physical contact along the interface and may be roughened to increase the effective coefficient of friction therebetween. Alternatively, the tapered surfaces may be in pressural interengagement without direct physical contact, but with a keying agent disposed between and embedded in the tapered surfaces along the interface to increase the effective coefficient of friction therebetween, particularly where the joint must resist relative bodily displacement of the tapered surfaces under torsional stress.

There is a tendency for stress concentrations to exist in the rods or tubings at the corresponding ends of the interfaces between the tapered surfaces of the joints. To relieve such a stress concentration, the corresponding end portion of one of the members may be further tapered adjacent the corresponding end of the interface between the tapered surfaces.

Preferably, in instances where adjacent rod or tubing ends are interconnected by couplings, the rod or tubing ends are cold worked to provide same with higher unit yield strengths than the nominal yield strengths of the bodies of the rods or tubings, thereby increasing the over-all strengths of the joints.

In most of the friction-type joints hereinafter consid-

ered, the tapered surfaces are unthreaded and the joints are made up by relative axial displacement of the inner and outer members without relative rotation thereof. In some instances, however, the tapered surfaces may be provided with shallow, wide, tapered threads having flat crest and root surfaces which form the pressurally inter-engaged tapered surfaces serving to frictionally prevent relative body displacement of the inner and outer members. In this instance, the threads merely serve to relatively axially displace the inner and outer members in response to rotation thereof, the inner and outer members being held together primarily by friction resulting from pressural interengagement of the root and crest surfaces, and only incidentally by any mechanical interlock between the threads.

With the foregoing as background, a primary object of the invention is to provide a method of and apparatus for producing the desired high hoop tension and compression stresses in the outer and inner members, which high stresses are necessary to create the desired high engagement pressure between the tapered surfaces thereof.

More specifically, a basic object of the invention is to provide a method of and apparatus for achieving the desired high hoop tension and compression stresses by shrinking the outer member on the inner, and, more particularly, by shrinking the outer member on the inner hydraulically. This permits the joint to be made up easily, and also permits the joint to be broken readily.

An important object is to provide a method of and apparatus for hydraulically shrinking the outer member on the inner which involves stressing the materials of the outer and inner members substantially to, but not quite to, their yield points to achieve the maximum possible engagement pressure between the tapered surfaces of the members, whereby to achieve maximum joint strength.

Still more specifically, an important object of the invention is to provide a method of and apparatus for injecting a fluid, such as oil, into an axially central region of the interface between the tapered surfaces of the inner and outer members under sufficient pressure to stress the materials of these members substantially to, but not quite to, their respective yield points in the central region, which results in radial separation of the tapered surfaces in such region. The injected fluid is prevented from escaping from the central region by sealing engagement of the tapered surfaces in annular sealing regions at opposite ends of the central region.

In making up the tapered joint in accordance with the foregoing, the inner and outer members are relatively moved axially into successively further inserted positions of the inner member as the pressure of the fluid injected into the central region of the interface builds up, thereby maintaining the tapered surfaces in sealing engagement in the sealing regions at the ends of the central region. When the injection pressure and the axial make up force reach their maximum values, the joint is fully made up and the pressure of the injected fluid in the central region is reduced substantially to atmospheric to permit outward expansion of the contracted portion of the inner member and inward contraction of the expanded portion of the outer member, thereby producing the desired high engagement pressure between the tapered surfaces of the two members with hoop tension and compression stresses in the outer and inner members substantially, but not quite, equal to the yield points of the materials of these members.

In breaking the joint with the method and apparatus of the invention, the foregoing procedure is essentially reversed, the pressure of the injected fluid in the central region serving to separate the tapered surfaces of the inner and outer members in this region so that the inner and outer members may be axially separated. Such axial separation is produced entirely by, or at least aided by, the action of the pressure of the injected fluid on the projected areas of the tapered surfaces.

Only relatively light engagement pressures are necessary in the sealing regions to prevent the escape of the injected fluid from the central region in making up and breaking the joint, so that, with the foregoing procedure, the joint can be made up easily, and broken readily, without galling the tapered surfaces, irrespective of whether they are unthreaded or threaded. Consequently, the joint can be made up and broken repeatedly in accordance with the invention without impairing the effectiveness of the tapered surfaces, which is an important feature.

Another object of the invention is to provide a method of and apparatus for injecting fluid into the central region of the interface between the tapered surfaces of the inner and outer members of the joint through a radial port in the outer member opening on the internal tapered surface of such member at approximately its axial center or midpoint. A feature of such a friction-type joint is that the injection port in the outer member may be left open in the use of a tubing string incorporating the joint, with the result that any fluid under high pressure within the tubing string leaking into the interface between the tapered surfaces is bled off through the open port to prevent such internal pressure within the tubing string from tending to break the joint.

A further object of the invention is to provide an apparatus comprising an injection means which is biased into engagement with the outer member of the joint around the injection port therein by the pressure of the injected fluid so as to maintain a fluid-tight seal during injection.

Another important object of the invention is to provide an apparatus which includes two sets of radially movable jaws engageable with a tubing or rod string on opposite sides of a friction-type joint therein which is to be made up or broken, one of the sets of jaws being axially movable toward or away from the other to insert the inner member into, or withdraw it from the outer member.

In making up a joint of the type wherein the tapered surfaces are unthreaded, the hereinbefore-discussed axial make up force is developed by biasing the axially-movable set of jaws toward the other set, preferably hydraulically. In breaking a joint of this type, the axially-movable set of jaws is moved away from the other set hydraulically, or is permitted to move away from the other set by the action of the pressure of the injected fluid on the tapered surfaces of the joint, being hydraulically restrained in this instance.

In making up or breaking the hereinbefore-discussed threaded type of joint, the required relative axial displacement of the inner and outer members is produced by the threads in the central region of the interface between the tapered surfaces thereof in response to rotation of one member relative to the other. An object in this connection is to provide means, preferably hydraulic motor means, for rotating one of the sets of jaws relative to the other about the axis of the joint.

A further important object of the invention is to provide an apparatus having indexing means for accurately registering the fluid injection means with the injection port in the outer member, both axially and circumferentially.

More particularly, an object is to provide means connected to the injection means for engaging an end surface of the outer member to axially register the injection means with the injection port. Another object is to provide means connected to the injection means and engageable with the end surface of the outer member in register with an indicium thereon for circumferentially registering the injection means with the injection port. An object in this latter connection is to provide a V-shaped key connected to the injection means and insertable into a V-notch in the end surface of the outer member of the joint.

The foregoing objects, advantages, features and results of the present invention, together with various other objects, advantages, features and results thereof which

will be evident to those skilled in the art to which the invention relates in the light of this disclosure, may be achieved with the exemplary embodiments of the invention described in detail hereinafter and illustrated in the accompanying drawings, in which:

FIG. 1 is a longitudinal sectional view of a coupling-type tubing joint construction, utilizing an external coupling, which embodies the invention;

FIG. 1a is a graph pertaining to one of the joints of the joint construction of FIG. 1;

FIG. 2 is a longitudinal sectional view of a coupling-type tubing joint construction, utilizing an internal coupling which embodies the invention;

FIG. 2a is a graph pertaining to one of the joints of the joint construction of FIG. 2;

FIG. 3 is a view similar to FIG. 1, but showing an alternative external-coupling-type tubing joint construction of the invention;

FIGS. 4 and 5 are views similar to FIG. 2, but showing alternative internal-coupling-type tubing joint constructions of the invention;

FIGS. 6 and 7 are longitudinal sectional views of alternative tubing joints of the invention directly interconnecting tubings without separate couplings;

FIG. 8 is a longitudinal sectional view of a coupling-type rod joint construction of the invention;

FIGS. 9, 10 and 11 are fragmentary longitudinal sectional views illustrating, on greatly enlarged scales, various ways of providing high effective coefficients of friction in the tubing and rod joints of FIGS. 1 to 8;

FIGS. 12 and 13 are fragmentary longitudinal sectional views illustrating different ways of relieving stress concentrations in various of the tubing and rod joints of FIGS. 1 to 8;

FIG. 14 is a fragmentary longitudinal sectional view illustrating thread means for making up various of the tubing and rod joints of FIGS. 1 to 8;

FIG. 15 is an enlargement of a portion of FIG. 14;

FIG. 16 is a vertical sectional view of a coupling and uncoupling apparatus for making and breaking the tubing and rod joints of FIGS. 1 to 8;

FIGS. 17, 18, 19, 20, 21 and 22 are sectional views respectively taken along the arrowed lines 17—17, 18—18, 19—19, 20—20, 21—21 and 22—22 of FIG. 16;

FIG. 23 is a view, partially in elevation and partially in vertical section, of a coupling and uncoupling apparatus for making and breaking the joint of FIGS. 14 and 15, FIG. 23 being taken along the irregular arrowed line 23—23 of FIG. 24;

FIG. 24 is a top plan view of the apparatus shown in FIG. 23; and

FIG. 25 is a fragmentary sectional view taken along the arrowed line 25—25 of FIG. 24.

Tubing joint, external coupling

Referring initially to FIG. 1, illustrated therein is a coupling-type tubing joint construction 20 of the invention comprising an external coupling 22 the respective end portions or ends 24 and 26 of which receive therein, in closely spaced relation, adjacent end portions or ends 28 and 30 of tubings 32 and 34 forming a tubing string 36. The coupling and tubing ends 24 and 28 form a tubing joint 38 and the coupling and tubing ends 26 and 30 form a tubing joint 40. The two tubing joints 38 and 40 are identical so that only the former will be considered.

The inner member of the tubing joint 38, i.e., the tubing end 28, is provided with a tapered outer surface 42 which converges axially inwardly relative to the coupling 22. The outer member of the tubing joint 38, i.e., the coupling end 24, is provided with a complementary tapered inner surface 44. The two tapered surfaces 42 and 44 are pressurally interengaged along the interface therebetween with a high engagement pressure induced by a high hoop tension stress in the coupling end 24 and an opposing high hoop compression stress in the tubing end 28.

As will be discussed in detail hereinafter, the axial length of the tapered surfaces 42 and 44 in pressural interengagement with each other is so related to the high engagement pressure between the tapered surfaces and the effective coefficient of friction therebetween as to produce a frictional resistance to relative bodily displacement of the tapered surfaces, either axially or circumferentially, sufficiently high to develop a joint strength at least nearly equal to the yield strength of the tubing 32. As will be discussed, the strength of the joint 38 may also attain or exceed the ultimate strength of the tubing 32.

The foregoing high frictional resistance to relative bodily displacement of the tapered surfaces 42 and 44 is preferably achieved by shrinking the coupling end 24 onto the tubing end 28, and particularly by hydraulically shrinking the coupling end onto the tubing end. Considering how this may be accomplished, the coupling end 24 is provided at approximately the axial midpoint of its tapered surface 44 with a port 46 for injecting a fluid, such as oil, under high pressure into the axially central region of the annular interface between the tapered surfaces 42 and 44. The port 46 communicates at its inner end with an internal annular groove 48 in the coupling end 24, and is provided at its outer end with a radially-inwardly-convergent annular seat 50 for a suitable fluid injection nozzle.

In making up the tubing joint 38, the tubing end 28 is inserted in the coupling end 24 until the tapered surface 42 engages the tapered surface 44 in the central region of the interface therebetween and in annular sealing regions on axially opposite sides of the port 46. Oil, or other fluid, under high pressure, which pressure may be as high as 30,000 p.s.i., or more, is then injected into the annular central region of the interface between the two tapered surfaces, at the same time applying an axial make up force to the coupling 22 and the tubing 32 tending to further insert the tubing end 28 into the coupling end 24. The high fluid pressure within the central region of the interface expands the adjacent portion of the coupling end 24 outwardly and contracts the adjacent portion of the tubing end 28 inwardly, without, however, breaking contact in the annular sealing regions on axially opposite sides of the central region so long as a sufficiently high axial make up force is applied. This make up force must be high enough to resist the action of the injection pressure on the axially projected areas of the tapered surfaces 42 and 44. Thus, the injected fluid is trapped in the annular central region of the interface.

As the pressure of the trapped fluid builds up, the coupling and tubing ends 24 and 28 are caused to be moved axially toward each other by the axial make up force to increase the extent to which the tubing end is inserted into the coupling end. After the maximum injection pressure and the maximum axial make up force for which the tubing joint 38 is designed have been reached, the tubing end 28 is in effect "bottomed" within the coupling end 24. (Such "bottoming" is solely the result of interengagement of the tapered surfaces 42 and 44, there being no annular shoulders, or the like, to artificially limit insertion.) Then, the application of the injection pressure is discontinued and the excess injected fluid is permitted to escape through the port 46. This permits the outwardly expanded portion of the coupling end 24 to contract inwardly, and simultaneously permits the inwardly contracted portion of the tubing end 28 to expand outwardly. The result is that the coupling end 24 is shrunk onto the tubing end 28 with a high engagement pressure determined by the maximum injection pressure and the maximum axial make up force.

It will be apparent that, in order to break the tubing joint 38, a similar procedure is followed. The injection pressure acting on the axially projected areas of the tapered surfaces 42 and 44 is normally sufficient to produce axial separation of the coupling and tubing ends 24

and 28. Actually, it may be necessary to restrain such axial separation.

When making up and breaking the tubing joint 38, the major portions of the tapered surfaces 42 and 44 intermediate the ends thereof are physically separated by the injected fluid, the latter being trapped in the central region of the interface with contact pressures between the tapered surfaces at the ends of the interface which are not excessively high. Consequently, galling of the tapered surfaces 42 and 44 in response to relative axial movement thereof in making up and breaking the joint 38 does not occur despite very high engagement pressures between the tapered surfaces when the joint is made up. Consequently, the joint 38 may be made up and broken repeatedly.

Another way of making up the tubing joint 38 is to jab the tubing end 28 into the coupling end 24, using a suitable lubricant between the tapered surfaces 42 and 44, by means of a sudden application of stored energy sufficiently high to produce the desired hoop tension and hoop compression stresses in the tubing and coupling ends, thereby producing the desired high engagement pressure between the tapered surfaces. To prevent galling of the tapered surfaces 42 and 44 in using this jab method of making up the tubing joint 38, the nature of the lubricant applied to the tapered surfaces must be such as to prevent extrusion of all of it out of the interface. Suitable lubricants are highly viscous liquids or heavy greases. Such lubricants may have mixed therewith suitable keying particles adapted to embed themselves in the tapered surfaces 42 and 44 to increase the effective coefficient of friction therebetween, as will be discussed hereinafter in connection with FIG. 11. Various stored energy sources capable of producing a sudden energy output sufficiently high to induce the desired hoop tension and hoop compression stresses in the coupling and tubing ends 24 and 28 may be used. Examples are an explosive charge, a high pressure gas-type accumulator, a high pressure liquid-type accumulator, and the like. Such energy sources may be connected to jaws engaging the tubings 32 and 34 in much the same manner that the two sets of jaws 88 engage them in FIG. 16. This jab method normally would be used where the joint 38 is permanent, as in a casing joint.

An annular seal 52, shown as located in an external annular groove in the tubing end 28 adjacent its innermost extremity, may be disposed between the tapered surfaces 42 and 44 adjacent the inner end of the interface therebetween. This seal prevents any internal pressure which may be developed in the tubing string 36 in use from being applied to the interface between the tapered surfaces 42 and 44 to tend to break the tubing joint 38. Any internal fluid which may leak past the annular seal 52 into the interface between the tapered surfaces 42 and 44 escapes by way of the annular groove 48 and the port 46. Consequently, no joint-loosening pressure can build up in the interface, being constantly bled off.

It will also be noted from the foregoing that any internal pressure which may exist in the tubing string 36 in use merely tends to tighten the tubing joint 38 since it acts outwardly on the tubing end 28 to tend to expand it into more positive engagement with the coupling end 24. To prevent the internal pressure from having any significant expanding effect on the coupling 22 itself, the axial separation between the innermost extremities of the two tubing ends 28 and 30 is kept as small as practicable to minimize the coupling area on which the internal pressure can act.

With the foregoing as background, various important considerations of the invention which enter into the structure of the tubing joint 38, and into the materials used for the coupling 22 and the tubing 32, will now be discussed. It should be kept in mind that, with exceptions which will be pointed out, these considerations are also

applicable to the tubing and rod joint species of the invention which will be described hereinafter.

In general, the axial length of the tapered surfaces 42 and 44 in pressural interengagement with each other, the engagement pressure between the tapered surfaces resulting from the hoop tension and compression stresses in the coupling and tubing ends 24 and 28, and the effective coefficient of friction between the surfaces, are so related as to produce a frictional resistance to relative bodily displacement of the tapered surfaces sufficiently high to develop a high-strength friction-type tubing joint 38, the joint strength being at least nearly equal to the nominal yield strength of the tubing 32 and, under some conditions, at least nearly equal to, or even exceeding, the ultimate strength of the tubing.

More particularly, the joint strength may be increased by increasing the axial length of pressural interengagement between the tapered surfaces 42 and 44, the effective coefficient of static friction therebetween, or the engagement pressure therebetween. To avoid an excessively long tubing joint 38, the axial length of the tapered surfaces 42 and 44 is preferably kept as small as possible, which means that it is necessary to make the engagement pressure and the effective coefficient of friction as high as possible, at the same time keeping the included angle of the tapered surfaces relatively small.

Considering the matter of the axial length of the interface between the tapered surfaces 42 and 44 in more detail, this length must be at least about 0.5 times the outside diameter of the body of the tubing 32 to obtain the desired high joint strength. However, the maximum axial length of the interface may be as much as about 6.0 times the outside diameter of the tubing 32 without being excessive for some applications, but is preferably not more than about 3.0 times the outside diameter of the tubing to be commercially practicable for all applications. (These ranges of ratios of the axial interface length to the outside diameter of the elongated element of the joint are also applicable to the other tubing and rod joint species hereinafter disclosed.)

With tubings which may be classed as thick walled, the hoop stress in the metal, when the tubing is subjected to either internal or external pressure, will vary from inside to outside, and the maximum hoop stress in the metal must be considered. The length, L , of pressural interengagement between the tapered surfaces 42 and 44, based upon the maximum hoop stress, may be determined from the equation

$$L = \frac{S_T}{S_H} \frac{d_1^2 + d_2^2}{4d_1(f - \tan \frac{1}{2}a)} \quad (I)$$

where

S_T is the axial tensile stress in the tubing 32 resulting from an axial load thereon,

S_H is the maximum hoop stress in the tubing end 28,

d_1 is the nominal outer diameter of the tubing,

d_2 is the nominal inner diameter of the tubing,

f is the effective coefficient of friction between the tapered surfaces, and

a is the included taper angle of the tapered surfaces 42 and 44.

With tubings which may be classed as thin walled, the radial variation in hoop stress in the tubing is less than for thick walled tubings and, while Equation I applies, it may be reduced to a somewhat simpler relation without serious error. This relation, for L , then becomes

$$L = \frac{S_T}{S_H} \frac{d_1 + d_2}{4(f - \tan \frac{1}{2}a)} \quad (II)$$

As the foregoing equations suggest, the axial length of the tapered surfaces 42 and 44 in pressural interengagement in the made up tubing joint 38 may be minimized in various ways. One way is to utilize hoop tension and compression stresses in the coupling and tubing ends 24

and 28 which are as high as possible, thereby achieving as high an engagement pressure between the tapered surfaces as possible. Preferably, in the absence of applied loads, the hoop stresses are close to but slightly less than the respective yield points of the materials of which the coupling and tubing ends 24 and 28 are made. With stresses close to the yield points, the interface length to elongated-element outside diameter ratio discussed above may be held within the preferred range of 0.5 to 3.0. (Various factors involved in selecting materials for the coupling 22 and the tubing 32 will be considered hereinafter, as will various factors entering into the selection of radial dimensions for the coupling and tubing ends 24 and 28.)

The other principal factor determining the length of the interface between the tapered surfaces 42 and 44 is, as hereinbefore indicated, the effective coefficient of friction, f , which is preferably made as large as possible. With the materials normally used for tubings and couplings in the oil industry, and with the surface roughness normally encountered, the effective coefficient of friction is in the neighborhood of 0.20. However, in some instances, a value as low as about 0.1 may be used without departing from the interface length to elongated-element outside diameter ratio ranges given above. Also, much higher effective coefficients of friction much higher than this, up to as high as the order of 0.80, can be achieved. For example, either or both of the tapered surfaces 42 and 44 may be roughened artificially, as by knurling, etching, sand blasting, plating in such a way as to roughen, and the like. Referring to FIG. 9 of the drawings, one of the tapered surfaces 42 and 44, preferably the tapered surface 44 of the coupling end 24, is shown as roughened by boring this coupling end with a tool shape and feed which will provide the tapered surface 44 with the equivalent of a fine thread 54 of buttress form and a sharp crest. Such thread 54 will greatly increase the unit contact pressure and may even slightly deform the mating tapered surface 42, while the two tapered surfaces 42 and 44 are pressurally interengaged throughout the substantially continuous interface therebetween (as suggested in FIG. 9), to provide the effect of an extremely shallow threaded engagement between the two tapered surfaces. This, however, does not interfere with making up and breaking the tubing joint 38 without relative rotation of the coupling and tubing ends 24 and 28. Even using a depth for the thread 54 of as little as 0.001 inch, or less, the effective coefficient of friction between the two tapered surfaces is increased to in the neighborhood of 0.40. (In this connection, it should be pointed out that the thread 54 is very greatly magnified in FIG. 9.) Consequently, all else being equal, this cuts in half the length of the interface between the tapered surfaces 42 and 44 which is required to achieve a given joint strength. Preferably, as shown in FIG. 9, the thread 54 does not fully embed itself in the tapered surface 42 to avoid permanently deforming it.

As shown in FIG. 10, the effective coefficient of friction may be increased by inserting between the tapered surfaces 42 and 44 a thin film 56 carrying a keying agent 58 which tends to embed itself into the tapered surfaces under the effect of the pressural interengagement therebetween. (In this case, pressural interengagement between the two tapered surfaces 42 and 44 occurs without direct physical contact, the tapered surfaces remaining physically separated by the film 56.) The film 56 may be of the order of 0.001 inch in thickness, and the keying agent 58 may comprise sharp-edged wire of diamond cross section carried by the film 56, the maximum transverse dimensions of the wire being of the order of 0.010 inch. The keying agent 58 may comprise a single, helical piece of wire, or it may comprise a plurality of pieces of wire. With this construction, the effective coefficient of friction may also be increased to in the neighborhood of 0.40.

Turning to FIG. 11, illustrated therein is a keying agent comprising particles of a hard material, such as tungsten

carbide, or the like, which are disposed between and which tend to embed themselves in the tapered surfaces 42 and 44 (which may be in actual physical contact between the keying particles). The keying particles 60 preferably have maximum transverse dimensions of the order of 0.002 inch and will increase the effective coefficient of friction between the tapered surfaces to of the order of 0.50. The keying particles 60 may be introduced into the interface between the tapered surfaces 42 and 44 in the fluid used in shrinking the coupling end 24 onto the tubing end 28, or in the lubricant used in jabbing the tubing end into the coupling end. Alternatively, they may be carried by a film corresponding to the film 56, in which case the film prevents direct physical contact between the tapered surfaces. Another alternative, for a permanent joint, is to use as a fluid for shrinking the coupling end 24 onto the tubing end 28 an adhesive which may also have keying particles similar to the keying particles 60 suspended therein. For example, an epoxy resin might be used. With this construction, an extremely high effective coefficient of friction can be achieved.

The included angle of the tapered surfaces 42 and 44 enters into the axial length of engagement of the surfaces, but only to the extent of reducing the influence of the effective coefficient of friction by the tangent of one half its value. Theoretically, the included taper angle could be 0° , but, as a practical matter, to facilitate insertion of the tubing end 28 into the coupling end 24, and to limit the variation in depth of insertion of the tubing end into the coupling with practical diameters and angle tolerances the included angle taper should be not less than about $0^\circ 30'$. The maximum included taper angle should not be more than about 4° where, as shown in FIG. 1 of the drawings, the wall thicknesses of the coupling and tubing ends 24 and 28 vary in the axial direction as the result of forming the tapered surfaces 42 and 44 by machining. It will be noted that the wall thickness of the tubing end 28 decreases in the direction of taper of the tapered surface 42, while the wall thickness of the coupling end 24 increases in the direction of taper of the tapered surface 44. This reduction in wall thickness should be limited to about 20%.

FIG. 3 of the drawings shows a tubing joint construction 20a which is similar to the tubing joint construction 20, corresponding parts being identified by the same reference numerals plus the suffix "a." In this case, the wall thicknesses of the coupling and tubing ends 24a and 28a are constant despite the taper of the surfaces 42a and 44a. This effect is achieved by flaring the entire coupling end 24a with the desired taper and by correspondingly tapering the entire tubing end 28a. To avoid reducing the net inside diameter of the tubing end 28a at its innermost extremity, the tubing end may initially be expanded, as indicated at 29a. Since the coupling and tubing ends 24a and 28a have constant wall thicknesses, they are capable of withstanding higher hoop tension and hoop compression, respectively. The effect of this is that the included taper angle of the surfaces 42a and 44a may be higher than with the tapering wall thicknesses of the coupling and tubing ends 24 and 28. With this construction, the included taper angle may range from $0^\circ 30'$ to as high as in the neighborhood of 18° , the upper limitation being determined primarily by the maximum permissible outside diameter of the tubing joint.

The foregoing effective coefficient of friction and included taper angle ranges are also applicable to the tubing and rod joint species hereinafter disclosed.

Turning now to a discussion of still other important considerations involved in the tubing joint 38, it will be recalled that the high hoop tension and compression stresses in the coupling and tubing ends 24 and 28 respectively establish axial compression and tension stresses in the coupling and tubing ends which, according to Poisson's ratio, are, for steel, approximately equal to 0.3 times the respective hoop tension and compression stresses.

Consequently, an axial tension load applied to the tubing 32 tends to decrease the initial axial compression stress in the coupling end 24 and to increase the initial axial tension stress in the tubing end 28, the compression stress in the coupling end 24 reversing and becoming a net axial tension stress upon application of a sufficiently high axial tension load. Because of this effect, the wall thickness of the coupling end 24 can be reduced, and can be further reduced by utilizing for the coupling 22 a material having a higher yield strength than the material of the tubing end 28. Thus, the coupling 22 can be considerably thinner than the tubing 32, as shown in FIG. 1 of the drawings. This is important because it reduces the over-all diameter of the tubing joint 38, which is of significance in areas, such as oil wells, where space is at a premium.

One effect of such a relatively thin coupling 22 is that, when an axial tension load is applied to the tubing 32, the coupling end 24, on the average, contracts more than the tubing end 28. Therefore, under these conditions, the engagement pressure between the tapered surfaces 42 and 44 actually increases with an increase in the tension load, as long as the stresses in the coupling and tubing ends are below the yield stresses. This is important because it increases the strength of the tubing joint 38.

As the axial tension stress in the tubing end 28 exceeds the tensile yield stress, with the stress in the coupling still within the elastic limit, the tubing end will contract faster than the coupling end 24, with the result that the engagement pressure between the tapered surfaces 42 and 44 will be reduced, and with the ultimate result that the tubing joint 38 will fail by pulling the tubing end out of the coupling end. This effect is heightened by the initial axial tension stress in the tubing end 28 induced by the shrink fit between the coupling and tubing ends. As the axial tension load on the tubing 32 is progressively increased, the axial tension stress in the tubing 32 first exceeds the yield strength in tension near or within the interface between the tapered surfaces 42 and 44. The result is that the tubing joint 38 fails by necking down of the tubing end 28, starting near the outer extremity of the coupling end 24, and progressing axially into the interior of the coupling end.

To offset the foregoing effect and thus obtain a tubing joint 38 having a higher strength in tension, several alternatives are possible. First, the elastic limit of the tubing end 28 may be increased by cold working. Second, the tubing end 28 might be provided with a greater wall thickness than the nominal wall thickness of the tubing 32. Third, both the elastic limit and the wall thickness of the tubing end 28 can be increased by cold working. By cold working the tubing end 28 to increase its elastic limit only, a joint strength at least equal to the yield strength of the tubing 32 can be attained. By cold working the tubing end 28 to increase its elastic limit and by cold upsetting it to increase its wall thickness, the strength of the tubing joint 38 can be made to exceed the ultimate strength of the tubing 32, whereupon failure occurs in the body of the tubing outside the joint 38. This effect may be achieved with a thickness increase of the order of 10% to 15%, which adds only a few hundredths of an inch to the outer diameter of the tubing end 28.

Various relationships involved in the tubing joint 38 are illustrated in FIG. 1a of the drawings. Referring thereto, the horizontal scale along the bottom of the graph represents the distance from the left-hand end of the interface between the tapered surfaces 42 and 44, expressed as a percentage of the axial length of the interface. The left-hand vertical scale represents the stresses in the coupling and tubing ends 24 and 28. The right-hand vertical scale represents dimensional relations between the coupling and tubing ends which will be defined hereinafter.

The graph of FIG. 1a assumes that the materials and thicknesses of the coupling and tubing ends 24 and 28, and the engagement pressure therebetween due to the shrink fit of the coupling end on the tubing end, are such

as to produce tension hoop and compression stresses in the coupling and tubing ends respectively less than or equal to the elastic limits of the materials thereof, and that these stresses are 100,000 p.s.i. and 60,000 p.s.i., respectively. Under these conditions, the coupling end 24 will be expanded 0.0033 inch per inch of diameter at the interface between the tapered surfaces 42 and 44, and the tubing end 28 will be contracted 0.002 inch per inch of diameter, for a total interference fit of 0.0053 inch per inch of diameter. Without any axial load on the tubing joint 38, this is constant along the length of the interface between the tapered surfaces 42 and 44 and is represented by the solid horizontal lines 71 in FIG. 1a.

Now, the effect of an axial tension load sufficient to stress the coupling and tubing ends 24 and 28 to the respective elastic limits of the materials thereof will be considered. (Initially, it will be assumed that the axial tension load is transferred between the coupling and tubing ends 24 and 28 in a linear manner along the length of the interface between the tapered surfaces 42 and 44. The corresponding stress distributions in the coupling and tubing ends 24 and 28 are respectively designated by the solid lines 73 and 75.) Taking into account the initial axial compression and tension respectively existing in the coupling and tubing ends 24 and 28, one effect of the axial tension load is to vary the interference fit or contact pressure between the tapered surfaces 42 and 44 as indicated by the broken line 81, the contact pressure being reduced adjacent the outer extremity of the coupling end 24 and being increased adjacent the inner extremity of the tubing end 28. This changes the axial stress distributions in the coupling and tubing ends 24 and 28 along the interface, the corrected stress distributions in the coupling and tubing ends being represented by the broken lines 77 and 79, respectively. The stress transfer between the coupling and tubing ends 24 and 28, with the foregoing nonlinear variations along the interface, requires a slight relative axial movement of the coupling and tubing ends which is variable along the interface, this being indicated by the solid line 83. Since the surfaces 42 and 44 are tapered, the relative movement therebetween represented by the line 83 will reduce the engagement pressure between the surfaces and the transfer of stress from the tubing end 28 to the coupling end 24 by an amount depending on the included taper angle. These effects would seem to detract from the possibility of friction joints of a strength desired by the invention. It has been determined, however, that the loss of interference fit or engagement pressure due to relative axial movement of the coupling and tubing ends 24 and 28 is very small. The loss of interference fit at an included taper angle of as much as 10° is only about 0.00029 inch per inch of diameter, which is insignificant as compared to the initial interference fit of 0.0053 inch per inch of diameter in the absence of an axial tension load.

Throughout all of the foregoing discussion of the tubing joint 38, it has been assumed that the moduli of elasticity of the materials of the coupling and tubing ends 24 and 28 are substantially equal. This assumption holds for coupling and tubing ends of steel even if the two members are made of steels having quite-different physical properties. With the steels normally used for oil well tubings and couplings, the variation in modulus of elasticity will not be more than a few percent, which has only a negligible effect on the strength of the tubing joint 38. However, a significant effect can be achieved by utilizing for the coupling 22 a material having a relatively low modulus of elasticity, but as high a strength as possible, and by using for the tubing 32 a material having a relatively high modulus of elasticity. For example, high strength aluminum alloys might be used for the coupling 22 and steel for the tubing 32. With such materials, the coupling end 24 would contract more than twice as much as the tubing end 28 for a given axial tension load, thereby producing a very substantial increase in the contact

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pressure between the tapered surfaces 42 and 44 as the axial tension load is increased. With such a construction, a joint strength at least as high as the ultimate tubing strength can readily be achieved. However, it would be necessary to utilize a relatively thick walled coupling 22 because of the present impossibility of obtaining materials having a modulus of elasticity which is low as compared to that of steel, but having a strength which is as high as that of steel. Nevertheless, where the wall thickness of the coupling 22 is not a factor, such a construction is entirely practical.

If the engagement pressure between the coupling 22 and the tubings 32 and 34 is substantially uniform throughout the interfaces of the respective tapered surfaces, stress concentrations are produced in the tubings at the ends of the coupling. To reduce such stress concentrations, the coupling extremities may be provided with additional tapers, either internal or external, to taper the engagement pressures toward zero at the coupling extremities. Referring to FIG. 12 of the drawings, the tapered surfaces 62 and 64 are shown as having constant and equal taper angles throughout most of the interface therebetween. However, the tapered surface 64 of the coupling end 26 is shown as provided at its extremity with an end portion 66 having, for a distance of about 25% of the engagement length, a slightly higher taper angle, e.g., having an included taper angle of about 30° higher than the included taper angle of the surfaces 62 and 64. This difference in the taper angle which is exaggerated in FIG. 12, is sufficient to reduce the contact pressure to zero, or a low value, at the extremity of the coupling end 26. The resulting tapering off of the engagement pressure toward the extremity of the coupling end 26 minimizes, or avoids entirely, any stress concentration in the tubing 34 at the coupling extremity. (With this means of reducing stress concentrations, the value of L in the equations hereinbefore given becomes the length of the interface between the tapered surfaces 62 and 64 up to the point where the taper of the surface 64 changes at 66.) Referring to FIG. 13, a similar effect may be achieved by externally tapering the coupling end 26, as indicated at 68.

The joint of the invention has previously been described as capable of being made up by application of an axial make up force without relative rotation of the inner and outer members. Shown in FIGS. 14 and 15 is an alternative tubing joint construction 20c wherein the axial make up force is produced, in response to relative rotation of the tubing and coupling ends 28c and 24c of a tubing joint 38c, by mating wide, shallow, tapered threads 72c and 74c on the tubing and coupling ends, respectively. The threads 72c and 74c are formed exclusively in axially-central regions of tapered surfaces 42c and 44c and have flat root and crest surfaces which constitute the tapered surfaces 42c and 44c. In other words, in the central region of the interface between the tapered surfaces 42c and 44c, the interface is formed by the root and crest surfaces of the thread 72c and the mating root and crest surfaces of the thread 74c. The threads 72c and 74c do not extend into the fluid-sealing regions at the ends of the tapered surfaces 42c and 44c, but extend only throughout central regions thereof. The threads 72c and 74c are complementarily tapered from zero depth at one of the fluid sealing regions to a maximum depth less than one-half the thread width at the other of the fluid sealing regions. While the threads 72c and 74c do provide some mechanical strength, the strength of the threaded joint of the invention is primarily due to friction between the tapered surfaces 42c and 44c as in the unthreaded species of the invention. The threads 72c and 74c function primarily to cause relative axial movement of the tubing and coupling ends 28c and 24c upon relative rotation thereof while fluid under high pressure is present in the central region of the interface during make up or breaking of the joint, such fluid being retained in the central region by the fluid sealing regions at the ends of the interface. Preferably,

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the threads 72c and 74c provide flank clearances, as shown in FIG. 15, to facilitate distribution of the injected fluid throughout the central region of the interface.

With the foregoing in mind, it will be apparent that the threads 72c and 74c may be quite shallow. For example, maximum depths ranging from 0.010 inch to 0.030 inch are adequate in small-diameter tubings (or rods), although they may be deeper for larger sizes. Preferably, the threads are modified square threads, actually trapezoidal threads, the flanks of which include angles of the order of 10°. This threaded arrangement for making up and breaking the tubing joint 38c may be applied to any of the other joints described hereinafter.

Tubing joint, internal coupling

Referring to FIG. 2 of the drawings, illustrated therein is a tubing joint construction 120 which is generally similar to the tubing joint construction 20, the various components of the tubing joint construction 120 being identified by reference numerals higher by one hundred than those used in connection with the corresponding components of the tubing joint construction 20.

Considering the differences between the tubing joint 138 and the tubing joint 38, the coupling end 124 is inserted into the tubing end 128 and the fluid injection port 146 is formed in the tubing end. The annular seal 152 for minimizing leakage into the interface between the tapered surfaces 142 and 144 is carried by the coupling end 124 adjacent its extremity. To permit providing the coupling 122 with an inner diameter equal to the inner diameter of the tubing 132, the tubing end 128 is expanded or belled. This is preferably done by cold working to increase the elastic limit of the tubing material within the tubing end 128.

In general, the discussion presented previously in connection with the tubing joint 38 applies to the tubing joint 138. In other words, thick-walled and thin-walled Equations I and II hereinbefore given apply. The previously presented ranges of ratios of axial interface length to elongated-element outside diameter, ranges of effective coefficients of friction, and ranges of included taper angles, all apply also, as do the ways of increasing the effective coefficient of friction illustrated in FIGS. 9, 10 and 11 of the drawings. Stress concentrations in the tubing 132 at the extremity of the coupling end 124 may be minimized by additional tapers of the coupling end 124, either internal or external, comparable to those shown in FIGS. 12 and 13, respectively. The tubing joint 138 may also be provided with threads for make up purposes similar to the threads shown in FIGS. 14 and 15. FIG. 2a is applicable to the tubing joint 138 and corresponds to FIG. 1a, FIG. 2a being a graph containing lines 171, 173, 175 and 181 respectively corresponding to the lines 71, 73, 75 and 81 of the graph of FIG. 1a. Corrected stress distribution lines similar to the lines 77 and 79 of the graph of FIG. 1a could be added to the graph of FIG. 2a, as could a relative-axial-movement line similar to the line 83.

While, as above outlined, most of the important considerations applicable to the tubing joint 38 are also applicable to the tubing joint 138, the internal coupling version does behave differently in a respect which is highly advantageous. More specifically, with the internal coupling 122, the tubing end 128 has an initial axial compression stress, due to the hoop tension stress therein, which reduces the net axial tension stress when the tubing 132 is subjected to an axial tension load. Therefore, without upsetting or severe cold working of the tubing end 128, the strength of the tubing joint 138 can easily be made to exceed the ultimate strength of the tubing 132. Consider, for example, a tubing 132 having a yield strength in tension of 40,000 p.s.i. The initial hoop tension stress in the tubing end 128, resulting from the high engagement pressure of the shrink fit, is at least nearly equal to the yield strength of the material. This gives an axial compression in the tubing end 128 of 0.3 times the

yield, which subtracts from the tensile stress in the tubing end, making the stress therein at the extremity of the internal coupling end 124 only about 28,000 p.s.i. when the tubing 132 itself is stressed to 40,000 p.s.i. When this yield point is exceeded the tubing will begin to neck down, but the point where failure starts will always be spaced from the coupling 122 because of the reduced tensile stress in the tubing end. As can be seen from FIG. 2a, the tensile load in the tubing increases the gripping action of the tubing onto the coupling at the end of the coupling 122. The magnitude of this increase is directly proportional to the tensile load up to the elastic limit of the material. When the stress is raised above the elastic limit in the tubing end, the contraction and gripping action is more than directly proportional to the increased tensile load. Tubing having a yield strength of 40,000 p.s.i. will have an ultimate strength of approximately 60,000 p.s.i. But since the net tensile stress in the tubing end is only 70% (1-0.3) of that at a point remote from the coupling even at the ultimate at that point, the stress in the tubing end is only slightly above the yield point. With higher strength steels the yield point and ultimate are even closer together. Therefore with this form of joint the gripping action always increases with load even when the tubing is stressed beyond the yield point and the axial stress in the tubing end is always less than in the body of the tubing. Consequently, with the internal coupling 122, failure occurs in the tubing 132 proper at a point spaced from the coupling, and never in the tubing joint 138 itself. The foregoing effect is amplified by the cold working necessary to expand or bell the tubing end 128 to receive the corresponding coupling end 124. Thus, with the tubing joint 138, a joint strength in excess of the ultimate strength of the tubings can easily be attained, which is an important advantage of the internal coupling species of the invention.

As in the case of the external coupling 22, the internal coupling 122 is preferably made of higher strength material and thinner than the tubing ends 128 and 130, thereby saving space, which is particularly important in an oil well. Further space savings can be achieved by utilizing for the internal coupling 122 a material having a modulus of elasticity much higher than the modulus of elasticity of the tubings 132 and 134. For example, the tubings can be made of steel and the internal coupling 122 of tungsten, which has a modulus of elasticity approximately two-thirds greater than that of steel. Consequently, the tubing ends will contract more than the internal coupling for the same tensile stress, thereby causing the tubing ends to grip the coupling more and more tightly as the stress is increased within the elastic limit. The same effect can also be obtained by using tubing of aluminum alloy with internal couplings of steel. Consequently, a joint strength in excess of the ultimate strength of the tubings can easily be achieved with an extremely thin internal coupling.

The coupling and tubing ends 124 and 128 are shown in FIG. 2 as tapering in thickness in proportion to the taper of the surfaces 144 and 142. This limits the hoop tension and compression which can be developed in the tubing and coupling ends 128 and 124 for the reasons hereinbefore discussed in connection with the tubing joint 38, thereby limiting the maximum taper angle for the surfaces 142 and 144. To permit utilizing a larger taper angle, the coupling and tubing ends may be provided with constant wall thicknesses in much the same manner as in the tubing joint construction 20a. Such a construction is shown in FIG. 4, wherein reference numerals differing from the reference numerals of FIG. 2 by the addition of the suffix "a" are utilized. The only difference in the construction of FIG. 4 is that the coupling and tubing ends 124a and 128a have constant wall thicknesses, and that the tubing end 128a is belled more at 129a to permit a minimum inside diameter for the coupling 122a equal to the inside diameter of the tubing 132a.

In instances where an inside diameter for the internal coupling less than the inside diameter for the tubings interconnected thereby is permissible, the tubing ends into which the coupling ends are inserted need not be belled. This is shown in FIG. 5 of the drawings, wherein reference characters differing from those used in FIG. 2 by the addition of the suffix "b" are employed.

Tubing joint, bell and spigot

Instead of frictionally interconnecting two tubings in end-to-end relation by means of a tubing joint construction which includes a coupling, they may be frictionally interconnected directly, without a coupling, by means of a bell-and-spigot-type of tubing joint 160, as shown in FIG. 6 of the drawings. The tubing joint 160 includes a tubing end 162, of a tubing 166, frictionally held in a tubing end 164, of a tubing 168, the two tubings forming a tubing string 170. The tubing ends 162 and 164 respectively have frictionally interengaged tapered surfaces 172 and 174. Fluid leakage into the interface between the tapered surfaces 172 and 174 is prevented by an annular seal 176 carried by the tubing end 162 adjacent its extremity. The outer tubing end 164 is provided with an injection port 178 communicating with an internal annular groove 180 therein to permit injection of fluid under high pressure in making up or breaking the tubing joint 160. The tubing end 164 is expanded or belled to receive the tubing end 162, the latter also preferably being expanded sufficiently to make its smallest inner diameter at least equal to the inner diameters of the tubings 166 and 168 to minimize any restriction to fluid flow through the tubing joint 160. In the tubing joint 160, the wall thicknesses of the tubing ends 162 and 164 are constant. In FIG. 7 is shown a tubing joint 160a which is identical to the tubing joint 160, except that the wall thicknesses of the tubing ends taper in proportion to the taper of the pressurally engaged surfaces thereof. The various components of the tubing joint 160a are identified by reference characters differing from the reference numerals of the corresponding components of the joint 160 by the addition of the suffix "a."

The various important considerations hereinbefore discussed in connection with the coupling-type tubing joint 38 are applicable to the tubing joints 160 and 160a, except for those involving the use of different materials, or materials with different physical properties, for the inner and outer members. In the tubing joints 160 and 160a, the inner and outer members, being integral with the tubings, must be formed of the same materials and materials having substantially the same physical properties, although certain physical properties can be varied by differentially cold working the inner and outer members.

Rod joint

Illustrated in FIG. 8 of the drawings is a rod joint construction 220 of the invention which is generally similar to the tubing joint construction 20, except that the elongated elements frictionally interconnected in end-to-end relation are solid rods, rather than tubings. In view of the similarity between the tubing joint construction 20 and the rod joint construction 220, the components of the latter are identified by reference numerals higher by two hundred than those used in conjunction with the corresponding components of the tubing joint construction 220. Thus, the rod joint construction 220 includes a rod joint 238 comprising an end 224 of a coupling 222 receiving therein an end 228, preferably cold upset, of a solid rod 232. The rod end 228 has an axially tapered surface 242 pressurally interengaged with an axially tapered internal surface 244 of the coupling end 224. The rod joint 238 may be made up and broken by injecting a fluid under high pressure into the axially central region of the interface between the tapered surfaces 242 and 244 through a port 246 formed in the coupling end 224 and communicating at its inner end with an internal annular dis-

tributing groove 248 in the coupling end 224. A radially-inwardly-converging annular seat 250 is provided at the outer end of the fluid injection port 246 to receive an injection nozzle, not shown. As in the case of the tubing joint construction 20, the two rod ends 228 and 230 are closely spaced within the coupling 222. The coupling 222 is provided therein within a bleed port 252 to drain from the space between the rod ends any injected fluid leaking thereinto so as to prevent a pressure build-up from interfering with making up of the joint 238, or its strength.

In general, the various important considerations hereinbefore discussed in connection with the external-coupling type tubing joint construction 20 are applicable to the rod joint construction 220 (except that equations differing from Equations I and II hereinbefore presented are applicable to the rod joint construction, as will be discussed hereinafter). In other words, the same ranges of ratios of axial interface lengths to elongated-element outside diameters, the same ranges of effective coefficients of friction, and the same ranges of included taper angles, are applicable. Additionally, similar material and material-characteristic relationships may be used in the rod joint construction 220. Also, the effective coefficient of friction between the tapered surfaces 242 and 244 may be increased in any of the ways shown in FIGS. 9, 10 and 11 of the drawings. Similarly, the rod joint construction 220 may be provided with a thread-type make up means, as shown in FIGS. 14 and 15. Further, while the coupling end 224 is shown as being of tapered wall thickness, it may be of constant wall thickness. Stress concentrations in the rod 232 may be relieved by externally tapering the extremity of the coupling end 224, as indicated at 254. Alternatively, the approach of FIG. 12 may be used. As another alternative, the included taper angle of the rod end 228 may be reduced slightly at the outer extremity of the coupling end 224.

Typical dimensions for the rod joint construction 220 when incorporated in an oil well sucker rod string 236 will now be given merely for purposes of illustration. FIG. 8 of the drawings shows the rod joint construction 220 drawn to scale to represent the true proportions of the joint construction when applied to sucker rods 232 and 234 having a nominal diameter of 0.875 inch. Considering the rod joint 238 as typical, the rod 232 is upset to approximately 1.05 inches in diameter at the axial midpoint on the tapered surface 242, this upset being much less than that required in an ordinary threaded sucker rod joint wherein the entire load is taken mechanically by the threads. The included taper angle of the surfaces 242 and 244 is 4° and the material of the coupling 222 is selected to provide a yield strength about 50% above that of the material of the sucker rod 232. The outer diameter of the coupling 222 is approximately 1.56 inches, which again is a smaller value than the corresponding dimension of an ordinary threaded sucker rod joint. Assuming a surface treatment for the tapered surfaces 242 and 244 such as to give an effective coefficient of friction of 0.3, the length of pressural interengagement of the tapered surfaces required to provide the rod joint 238 with a pull-out strength equal to the yield strength of the rod 232 is approximately 1.96 inches. This results in an over-all length for the coupling 222 of not more than about 5 inches, which is of the same order of magnitude as the coupling of an ordinary threaded sucker rod joint which relies on the mechanical action of the threads, and not on friction.

Considering equations for the rod joint 238 similar to those hereinbefore presented in connection with the tubing joint 38, in most instances, it is necessary to regard the coupling end 224 as thick walled members. The rod end 228 is not critical, except that the hydraulic pressure to expand the coupling end, and the engagement pressure between the coupling end and the rod end, cannot be more than one-half the allowable unit compressive stress

in the material used for the rod. Considering a rod having an upset end, then the length of pressural interengagement required may be determined in accordance with the equation

$$L = \frac{S_R}{S_C} \frac{d_R^2}{d_2} \frac{d_1^2 + d_2^2}{d_1^2 + d_2^2} \frac{1}{4(f - \tan \frac{1}{2}a)} \quad (\text{III})$$

where

L is the axial length of the interface between the tapered surfaces 242 and 244,

S_R is the axial tensile stress in the rod 232 resulting from an axial load thereon,

S_C is the hoop tension stress in the coupling end 224, d_R is the nominal diameter of the rod,

d_1 is the outer diameter of the coupling,

d_2 is the inner diameter of the coupling at the axial midpoint of the interface,

f is the effective coefficient of friction between the tapered surfaces, and

a is the included taper angle of the tapered surfaces.

In the foregoing equation, the ratio S_R/S_C is preferably not more than 1.00. By using a high strength material for the coupling 222, e.g., a material having a strength about 50% higher than that of the rod 232, the ratio S_R/S_C may be of the order of 0.67. A further reduction to as low as 0.50 is possible. It is desirable to use as high strength a material as possible for the coupling 222 since, in view of the fact that it is a relatively small and light member, its cost is not a significant factor in the total cost of the rod string 236. Also, by using a hard, nongalling material for the coupling 222, wear as the result of rubbing against a tubing string in which it is disposed is minimized. Preferably, a nitrided steel is used for the coupling 222, such a material having a high strength combined with a very high surface hardness and resistance to galling in combination with either nitrided steel or other metals.

In some instances, e.g., for small-diameter rod joint constructions, the foregoing thick-walled equation may be replaced by the thin-walled equation

$$L = \frac{S_R}{S_C} \frac{d_R^2}{d_1 - d_2} \frac{1}{4(f - \tan a/2)} \quad (\text{IV})$$

It will be understood that the hereinbefore-described high-strength friction-type tubing and rod joints of the invention are illustrative only and that various other joints of this character are possible within the scope of the invention.

Generic equation for rod and tubing joints

An important feature of the invention is that various structural parameters of each of the tubing and rod joints hereinbefore disclosed may be related in a generic equation, hereinafter identified as Equation V, giving the minimum axial length, L, of pressural interengagement between the tapered surfaces of each joint which is necessary to obtain a joint strength at least substantially equal to the yield strength of the body portion of the elongated element of the joint. Normally, one or the other of the inner and outer members of each joint will be a critical member in the sense that it limits the strength of, i.e., determines the maximum strength of, the joint (although there may be instances where both members are critical). Equation V is based on the assumption that one of the members is critical, and reads

$$L = \frac{K_1 K_2 (\phi + 2d^2)}{4d(f - \tan a/2)} \quad (\text{V})$$

where

$K_1 = S_1/S_2$, S_1 being the tensile yield stress of the body portion of the elongated element of the joint, and S_2 being the hoop yield stress of the critical member thereof,

$K_2 = A_1/A_2$, A_1 being the cross sectional area of the body portion of the elongated element, and A_2 being

the cross sectional area of the critical member at the axial midpoint of the interface between the tapered surfaces,

f is the effective coefficient of friction between the tapered surfaces of the joint,

α is the included taper angle of the tapered surfaces,

d is the interface diameter of the critical member at the axial midpoint of the interface between the tapered surfaces, and

ϕ is zero when the inner member of the joint is the critical member, and is equal to $4A_1/\pi K_2$ when the outer member is the critical member

and where

$K_1 K_2$ is not greater than one.

In each of the friction joints of the invention, the critical member referred to in Equation V is the end portion of the elongated element of the joint if such end portion is tubular, but the critical member is the outer member if the end portion of the elongated element of the joint is solid and if the engagement pressure between the tapered surfaces of the joint does not exceed one-half the yield point of such solid end portion. Thus, in the various external-coupling and internal-coupling tubing joints disclosed, the tubing ends are the critical members. In the bell and spigot joint, the belled tubing end is critical, and, in the rod joint, the coupling is critical.

As hereinbefore explained, the value of L provided by Equation V is the minimum axial interface length to achieve a joint strength at least substantially equal to the yield strength of the body portion of the elongated element involved. However, the axial interface length preferably should not exceed $3L$. Alternatively, the point can be constructed with a maximum axial interface length limited by the previously-given ranges of the ratio of the axial interface length to the outside diameter of the elongated element of the joint.

Coupling and uncoupling apparatus 350

Turning now to FIGS. 16 to 22, illustrated therein is an apparatus 350 for making and breaking any of the unthreaded tubing or rod joint constructions hereinbefore disclosed. The apparatus 350 may be used for performing the method of the invention of making and breaking these joint constructions. It will be described relatively briefly herein, and will be considered in connection with the tubing joint construction 20 for convenience.

Referring particularly to FIG. 16, the apparatus 350 may be mounted in a vertical position over an oil well, not shown, into or out of which the tubing string 36 is being run. The apparatus 350 provides an axial, i.e., vertical, passageway 354 therethrough for the tubing string 36. The passageway 354 is shown as open on one side for lateral application to the tubing string, if desired.

In considering the apparatus 350 and its operation, it will be assumed that the lowermost tubing 34 and the coupling 22 have previously been frictionally interconnected by means of the joint 40, and that the uppermost tubing 32 and the coupling 22 are to be frictionally interconnected, or disconnected, in order to make up, or break, the tubing joint 38.

The apparatus 350 includes a base 356 having the form of a housing which provides two or more vertical cylinders 358 parallel to and spaced from the passageway 354. Reciprocable in the cylinders 358 are pistons 360 and supply of operating fluid under pressure to which is controlled by a valve 362. As will be apparent, when the valve 362 is in the position shown, it admits operating fluid under pressure from a supply line 364 into the lower ends of the cylinders 358 through a passage means 366. At the same time, the valve 362 connects a passage means 368, FIGS. 16 and 22, which passage means communicates with the upper ends of the cylinders 358, to an operating fluid return line 370. Under these conditions,

the pistons 360 are biased upwardly in their cylinders 358.

It will be noted that under the foregoing conditions, the supply line 364 is connected to the passage means 366 through an external annular channel 372 in the valve 362, and the passage means 368 is connected to the return line 370 through an external annular channel 374 in the valve.

In order to bias the pistons 360 downwardly in their cylinders 358, the valve 362 is moved upwardly, by means of a handle 376, into its uppermost position. Under such conditions, the external annular channel 372 in the valve 362 connects the operating fluid supply line 364 to the passage means 368 leading to the upper ends of the cylinders 358. At the same time, the passage means 366 leading to the lower ends of the cylinders 358 is connected to the operating fluid return line 370 by a passage means 378 through the valve 362 itself.

Thus, the pistons 360 may be moved upwardly or downwardly in their cylinders 358, as required by the hereinafter-described operation of the apparatus 350, by shifting the position of the valve 362.

The pistons 360 have connected thereto upwardly extending piston rods 382 having a crosshead 384 mounted thereon at their upper ends, the vertical passageway 354 for the tubing string 36 extending through the crosshead. In the operation of the apparatus 350, the tubing joint 38 is disposed between the base 356 and the crosshead 384.

Within the base 356 and the crosshead 384 are pairs of horizontally opposed cylinders 386 containing horizontally inwardly and outwardly movable pistons 388 terminating at their inner ends in jaws 390 adapted to grip the tubings 32 and 34, the upper jaws being adapted to grip the tubing 32 above the tubing joint 38 and the lower jaws being adapted to grip the tubing 34 below the tubing joint 40.

As will be apparent, with the two pairs of jaws 390 in engagement with the two tubings 32 and 34 as shown, upward movement of the crosshead 384, produced by positioning the valve 362 to deliver operating fluid under pressure to the lower ends of the pistons 360, will tend to break the tubing joint 38 (or the tubing joint 40). Conversely, downward movement of the crosshead 384, produced by setting the valve 362 in a position to deliver operating fluid under pressure to the upper ends of the pistons 360, is utilized in making up either tubing joint.

The two sets of jaws 390 are controlled by a valve 392, FIG. 21, which, in the position shown, admits fluid under pressure from an operating fluid supply line 394 into a passage means 396 leading to the outer ends of the cylinders 386 in the base 356. The piston rods 382 are provided therein with passage means 398 the lower ends of which are in constant communication with the passage means 396 for all positions of the pistons 360, and the upper ends of which communicate with the outer ends of the cylinders 386 in the crosshead 384. Thus, when the valve 392 is in the position shown in FIG. 21, the two sets of jaws 390 are simultaneously energized to grip the two tubings 32 and 34 on opposite sides of the tubing joint construction 20.

By rotating the valve 392 by means of a handle 400 connected thereto, the valve may be moved to a position wherein it cuts off the flow of operating fluid under pressure from the supply line 394, and connects the passage means 396 to an operating fluid return line or exhaust line 402. Under these conditions, the jaws 390 are de-energized to release the tubings 32 and 34. If desired, means, not shown, may be provided for automatically retracting the jaws 390 under such conditions.

The apparatus 350 includes a yoke or saddle 404 which, as best shown in FIG. 19, is provided therein with a radial cylinder 406 containing a piston-like injection nozzle 408 having a tapered inner end engageable with the tapered annular seat 50 in the coupling end 24 and

biased outwardly by a spring 409. The outer end of the cylinder 406 has connected thereto a supply line 410 leading to a suitable source, not shown, of fluid under high pressure for injection into the interface between the tapered surfaces 42 and 44 of the tubing end 28 and the coupling end 24, respectively. As previously indicated, this injection pressure may be of the order of ten to thirty thousand pounds per square inch. As will be apparent, the injection fluid pressure acts on the outer end of the injection nozzle 408 to maintain the inner end thereof in fluid tight engagement with the annular seat 50.

In the construction illustrated in FIG. 19, the saddle 404 is supported by the upper end of the coupling 22, the axial distance from an internal shoulder 411 on the saddle to the center line of the radial cylinder 406 being made equal to the distance from the end of the coupling to the centerline of the tapered seat 50. Axial alignment is therefore maintained by standardizing these dimensions. To provide radial alignment of the injection nozzle 408 with the seat 50 there is a V-notch 112 in the end of the coupling 22 in line with the seat 50. A tapered key 413 on the saddle 404 fits into the V-notch 412 and thus permits easy radial alignment of the nozzle 408 with the seat 50.

Operation of apparatus 350

Considering briefly the over-all operation of the apparatus 350, the various parts thereof are shown in the positions which they would occupy when breaking the tubing joint 38. In other words, the valve 392 is in a position to energize the jaws 390, the valve 362 is in a position to cause the pistons 360 to bias the crosshead 384 upwardly to separate the upper tubing end 28 from the coupling end 24, and fluid under high pressure is being injected into the interface between the tapered surfaces 42 and 44. Under these conditions, the tapered surfaces 42 and 44 are forced apart by radially inward contraction of the tubing end 28 and by radially outward expansion of the coupling end 24. Under such conditions, the tubing 32 may be axially separated from the coupling 22 readily by the pistons 360. It will be understood that the injection pressure acts on the projected area of the tapered surface 42 of the tubing end 28 so that, in actuality, it may be necessary to apply very little, if any, pressure to the lower ends of the pistons 360. In fact, under some conditions, it may be necessary to reverse the position of the valve 362 to restrain the tubing 32 against too rapid upward movement since the upward force applied by the injection pressure normally will be at least several hundred pounds even with half-inch oil well tubings, and may be many thousands of pounds with larger tubings. This point will be discussed in more detail hereinafter.

In using the apparatus 350 to make up the tubing joint 38, the foregoing procedure is reversed, i.e., the tubing 32 is displaced downwardly to insert or stab the end 28 thereof into the coupling end 24. To accomplish this, of course, the position of the valve 362 is such as to connect the operating fluid supply line 364 to the upper ends of the cylinders 358. Obviously, under such conditions, the jaws 390 are energized and fluid under high pressure is injected into the interface between the tapered surfaces 42 and 44 through the injection nozzle 408.

As previously suggested, the tubing 32 must be moved downwardly continuously relative to the coupling 22 as the injection pressure in the interface between the tapered surfaces 42 and 44 builds up. If this is not done, the sealing engagements of the end portions of these tapered surfaces will be broken and the injected fluid will leak out, thereby limiting the maximum injection fluid pressure attainable and the resultant contact pressure between the coupling end 24 and the tubing end 28.

The make-up force which must be applied to the tubing 32 in making up the tubing joint 38 as hereinbefore outlined depends on the taper of the surfaces 42 and 44, the

size of the tubing, the length of tapered surfaces, the grade of steel in the tubing, and the like. The taper length, i.e., the length of the tapered surfaces in pressural inter-engagement, required to obtain a joint strength equal, for example, to the yield point of the tubings 32 and 34 depends on the coefficient of friction and the shrink pressure, the latter being limited to a pressure which stresses the material in the tubing end 28 to the yield point. These factors are related, for a coefficient of friction of 0.20 and an included taper angle of 1° for the tapered surfaces 42 and 44, as set forth in the following table:

Tubing size			Taper length	J-55 thrust, lbs.	N-80 thrust, lbs.	P-105 thrust, lbs.
Nominal	I.D.	O.D.				
1/2	.622	.840	1.82	615	895	1,175
3/4	.824	1.050	2.34	960	1,390	1,830
1	1.049	1.315	2.98	1,505	2,190	2,870
1 1/4	1.380	1.660	3.82	2,400	3,490	4,580
1 1/2	1.610	1.900	4.40	3,145	4,570	5,990
1 3/4	1.660	2.000	4.59	3,485	5,060	6,650
2	1.995	2.375	5.46	4,910	7,150	9,360
2 1/2	2.441	2.875	6.65	7,200	10,500	13,750
3	2.992	3.500	8.10	10,675	15,500	20,400
3 1/2	3.476	4.00	9.33	13,900	20,200	26,600
4	3.958	4.50	10.60	17,650	25,700	33,700

In the foregoing table, the inside and outside diameters of the tubings and the taper lengths are given in inches. The thrust values in pounds are the forces which must be applied to obtain proper make up. The designations "J-55," "N-80" and "P-105" are standard tubing designations of the American Petroleum Institute, the numbers being the yield strengths of the materials in thousands of pounds per square inch.

The make-up force required varies inversely with the coefficient of friction. Thus, when the tapered surfaces 42 and 44 are roughened, as discussed with regard to FIGS. 9 to 11, the expanding pressures and the resulting make-up thrusts are materially reduced.

Coupling and uncoupling apparatus 460

Illustrated in FIGS. 23 to 25 is a coupling and uncoupling apparatus 460 for making up and breaking threaded friction-type joints of the invention, such as the tubing joint construction 20c. Basically, the apparatus 460 is identical to the apparatus 350 so that only the differences will be discussed, identical reference numerals being applied to identical parts.

In the apparatus 460, a crosshead 461 similar to the crosshead 384 is provided with a tubular upward extension 462 on which a rotor 464 is mounted by means of bearings 466 and 468. The rotor 464, which is rotatable about the axis of the tubing string 36c, carries a peripheral gear 470 driven by a pinion 472, FIGS. 24 and 25, on the output shaft of a rotary hydraulic motor 474 mounted on the crosshead 461. Flexible operating fluid supply and return lines 476 and 478 are connected to the motor 474.

The rotor 464 is provided adjacent its upper end with horizontal cylinders 480, shown as three in number, containing horizontally inwardly and outwardly movable pistons 482 terminating at their inner ends in jaws 484 adapted to grip the upper tubing 32c (assuming the joint 38c is to be made up or broken). The lower tubing 34c is gripped by the lower set of jaws 390 previously described. The upper jaws 484 are energized under the control of the valve 392 through the previously described passage means 398 in one of the piston rods 382, and through passage means 486 in the crosshead 461, passage means 488 in the crosshead extension 462, and passage means 490 in the rotor 464, the passage means 488 and 490 being in constant communication.

The injection means for injecting fluid under high pressure into the interface between the tapered surfaces 42c and 44c of the tubing joint 38c may be similar to that previously described in connection with the apparatus 350. However, the injection means of the apparatus 460 is shown as including a split collar 492 having pivoted sec-

tions which may be swung into position around the coupling 22c. One of these sections carries the injection nozzle 408, which is indexed axially and circumferentially in the same way as in the apparatus 350.

Operation of apparatus 460

In using the apparatus 460 with the tubing joint 38c, the lower set of jaws 390, and the upper set of jaws 484 on the rotor 464, are energized and deenergized by means of the valve 392 described previously. The valve 362 for applying pressure to the upper or lower ends of the pistons 360 is merely operated, in the apparatus 460, to lift the threaded lower end of the upper tubing 32c out of the coupling 22c and to stab it into the coupling. In actually making up or breaking the tubing joint 38c, the threads 72c and 74c do the work in response to rotation of the upper tubing 32c relative to the coupling 22c by the rotor 464. Under such conditions, it is contemplated that no pressure be applied to the pistons 360 controlling the vertical position of the crosshead 461. To achieve this, the valve 362 may be provided with a neutral position, not shown. Alternatively, pressure may be applied to the pistons 360 in a direction to assist the threads 72c and 74c in making up or breaking the tubing joint 38c.

As will be apparent, after the tapered and threaded lower end 28c of the upper tubing 32c has been stabbed into the upper end of the coupling 22c, and preferably hand tightened, the motor 474 is energized and fluid under high pressure is injected into the interface between the tapered surfaces 42c and 44c through the injection nozzle 408 in the manner hereinbefore described, such fluid being distributed throughout the central region of the interface by the flank clearances between the threads 72c and 74c. It will be understood that, under the foregoing conditions, the upper and lower sets of jaws 484 and 390 are energized. The motor 474 keeps making up the tubing joint 38c as the tubing end 28c is radially contracted and the coupling end 24c is radially expanded, thereby preventing loss of the injected fluid at the ends of the tapered surfaces 42c and 44c. Ultimately, when the tubing joint 38c is completely made up, the motor 474 stalls under the controlled pressure supplied to the motor through the supply line 476. The injection pressure in the central region of the interface between the tapered surfaces 42c and 44c is then released, whereupon the coupling end 24c shrinks onto the tubing end 28c. As previously pointed out, the strength of the tubing joint 38c is primarily due to this shrink fit, and the primary function of the threads 72c and 74c is in making up the joint. However, the mechanical interlock of the threads adds to the strength.

The procedure in breaking the tubing joint 38c is similar to the procedure in making up same, but reversed. Consequently, a further description is not necessary.

Although exemplary embodiments of the invention have been disclosed herein for purposes of illustration, it will be understood that various changes, modifications and substitutions may be incorporated in such embodiments without departing from the spirit of the invention as defined by the claims which follow.

What is claimed is:

1. A method of making up a high-strength, friction-type joint which is adapted to interconnect elongated elements, such as tubings or rods, and which includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces tapering substantially uniformly at corresponding small included angles throughout their axial lengths and being pressurably interengageable along an interface, said outer tubular member having a port therethrough opening on said inner tapered surface approximately at the axial midpoint thereof, and one of said members being an end portion of one of said elongated elements, said method including the steps of:

(a) relatively moving said inner and outer members together into an initial inserted position of said inner

member in which said tapered surfaces are in engagement in an annular central region of said interface and in annular sealing regions thereof at opposite ends of said central region;

- (b) injecting fluid through said port into said central region under a high pressure sufficient to expand said outer member and contract said inner member in said central region, while simultaneously relatively moving said members together into successively further inserted positions of said inner member to maintain said tapered surfaces in sealing engagement in said sealing regions;
- (c) then opening said port to low pressure to relieve the high fluid pressure in said central region and bring the expanded and contracted portions of said tapered surfaces together into pressural interengagement with a high engagement pressure therebetween induced by a high hoop tension stress in said outer member and an opposing high compression stress in said inner member; and
- (d) controlling the axial length of said interface, the effective coefficient of friction between said tapered surfaces, the pressure of the fluid injected into said central region of said interface, and the extent of further insertion of said inner member while the fluid at said pressure is in said central region, to produce a frictional resistance to relative bodily displacement of said tapered surfaces sufficiently high to develop a joint strength at least nearly equal to the yield strength of the elongated elements interconnected by said joint.

2. A method of making up a high-strength, friction-type joint which is adapted to interconnect elongated elements, such as tubings or rods, and which includes an outer tubular member and an inner member respectively adapted to be provided with complementary, inner and outer tapered surfaces tapering substantially uniformly at corresponding small included angles throughout their axial lengths and being pressurably interengageable along an interface, one of said members being an end portion of one of said elongated elements, said method including the steps of:

- (a) cold working said end portion of said one elongated element and forming the corresponding one of said tapered surfaces on said cold-worked end portion to produce said one member;
- (b) forming the other of said tapered surfaces on the other of said members;
- (c) relatively moving said members together into an initial inserted position of said inner member in which said tapered surfaces are in engagement in an annular central region of said interface and in annular sealing regions thereof at opposite end of said central region;
- (d) injecting fluid into said central region under high pressure sufficient to stress the materials of said inner and outer members in said central region to values close to, but less than, their respective yield points, whereby to expand said outer member and contract said inner member in said central region, while simultaneously relatively moving said members together into successively further inserted positions of said inner member to maintain said tapered surfaces in sealing engagement in said sealing regions; and then
- (e) opening said central region to low pressure to relieve the high fluid pressure in said central region and bring the expanded and contracted portions of said tapered surfaces together into substantially continuous pressural engagement with a high engagement pressure therebetween induced by a high hoop tension stress in said outer member and an opposing high compression stress in said inner member respectively substantially equal to, but slightly less

than, the stresses induced in said outer and inner members by said fluid pressure.

3. A method as defined in claim 2 in which said cold working of said end portion of said elongated element includes radial expansion thereof.

4. A method as defined in claim 2 in which the cold working of said end portion of said elongated element includes radial expansion followed by radial contraction thereof.

5. A method as defined in claim 4 in which said one elongated element is a tubing and in which the radial contraction of said end portion is continued until the smallest internal diameter of said end portion is substantially equal to the nominal internal diameter of said tubing.

6. A method as defined in claim 2 in which said cold working of said end portion includes axial upsetting of said end portion.

7. A method as defined in claim 2 including the step of roughening one of said tapered surfaces to produce crests separated by valleys of a depth no more than a few thousandths of an inch, said crests engaging the other tapered surface, at said high engagement pressure induced between said tapered surfaces upon relief of said fluid pressure, to provide a high effective coefficient of friction between said tapered surfaces.

8. An apparatus for making up or breaking a high-strength, friction-type joint which is adapted to interconnect elongated elements, such as tubings or rods, in end-to-end relation to form a string of such elements, and which includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces pressurally interengageable along an interface therebetween, said outer tubular member having a port therethrough opening on said inner tapered surface approximately at the axial midpoint thereof, and one of said members being an end portion of one of said elongated elements, including:

(a) injection means engageable with said outer member around said port therein for injecting a fluid through said port into a central annular region of the interface between said tapered surfaces under high pressure sufficient to expand said outer member and contract said inner member in said central region while the fluid is confined in said central region by engagement of said tapered surfaces in annular sealing regions of the interface at opposite ends of said central region;

(b) means connected to said injection means and engageable with an end surface of said outer member for registering said injection means with said port in said outer member; and

(c) means, including elements engageable with said string on opposite sides of said joint, for relatively moving said members toward each other to maintain said tapered surfaces in engagement in said sealing regions in making up said joint.

9. An apparatus for making up or breaking a high-strength, friction-type joint which is adapted to interconnect elongated elements, such as tubings or rods, in end-to-end relation to form a string of such elements, and which includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces pressurally interengageable along an interface therebetween, said tapered surfaces being defined by flat root and crest surfaces of wide, shallow, tapered threads on said members in a central annular region of said interface, said outer tubular member having a port therethrough opening on said inner tapered surface approximately at the axial midpoint thereof, and one of said members being an end portion of one of said elongated elements, including:

(a) a frame having a passageway therethrough for said joint and adjacent portions of said elongated elements;

(b) two sets of radially movable jaws spaced apart along said passageway and respectively engageable

with said string adjacent opposite ends of said joint;

(c) one of said sets of jaws being an axially movable set which is movable axially of said passageway toward and away from the other;

(d) one of said sets of jaws being a rotatable set which is rotatable relative to the other about the axis of said passageway;

(e) means for radially moving said jaws of said sets into and out of engagement with said string;

(f) injection means engageable with said outer member around said port therein for injecting a fluid through said port into said central region of the interface between said tapered surfaces under high pressure sufficient to expand said outer member and contract said inner member in said central region while the fluid is confined in said central region by engagement of said tapered surfaces in annular sealing regions of the interface at opposite ends of said central region;

(g) actuating means for axially moving said axially movable set of jaws toward and away from the other in making up and breaking said joint, respectively; and

(h) means for rotating said rotatable set of jaws relative to the other about the axis of said passageway to cause said threads to produce relative axial movement of said inner and outer members in making up and breaking said joint, said threads maintaining said tapered surfaces in engagement in said annular sealing regions in response to rotation of said rotatable set of jaws in a direction to advance said inner member into said outer member in making up said joint.

10. An apparatus for making up or breaking a high-strength, friction-type joint which is adapted to interconnect elongated elements, such as tubings or rods, in end-to-end relation to form a string of such elements, and which includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces pressurally interengageable along an interface therebetween, said outer tubular member having a port therethrough opening on said inner tapered surface approximately at the axial midpoint thereof, and one of said members being an end portion of one of said elongated elements, including:

(a) a frame having a passageway therethrough for said joint and adjacent portions of said elongated elements;

(b) two sets of radially movable jaws spaced apart along said passageway and respectively engageable with said string adjacent opposite ends of said joint;

(c) one of said sets of jaws being a movable set which is movable axially of said passageway toward and away from the other;

(d) means for radially moving said jaws of said sets into and out of engagement with said string;

(e) injection means engageable with said outer member around said port therein for injecting a fluid through said port into a central annular region of the interface between said tapered surfaces under high pressure sufficient to expand said outer member and contract said inner member in said central region while the fluid is confined in said central region by engagement of said tapered surfaces in annular sealing regions of the interface at opposite ends of said central region;

(f) means associated with said injection means and engageable with an end surface of said outer member, and including a V-shaped key insertable into a V-notch in said end surface, for axially and circumferentially locating said injection means in register with said port in said outer member; and

(g) actuating means for axially moving said movable set of jaws toward and away from the other in making up and breaking said joint, respectively.

11. An apparatus for making up or breaking a high-strength, friction-type joint which is adapted to intercon-

nect elongated elements, such as tubings or rods, in end-to-end relation to form a string of such elements, and which includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces pressurally interengageable along an interface therebetween, said outer tubular member having a port therethrough opening on said inner tapered surface approximately at the axial midpoint thereof, and one of said members being an end portion of one of said elongated elements, including:

- (a) a frame having a passageway therethrough for said joint and adjacent portions of said elongated elements;
- (b) two sets of radially movable jaws spaced apart along said passageway and respectively engageable with said string adjacent opposite ends of said joint;
- (c) one of said sets of jaws being a movable set which is movable axially of said passageway toward and away from the other;
- (d) means for radially moving said jaws of said sets into and out of engagement with said string;
- (e) injection means engageable with said outer member around said port therein for injecting a fluid through said port into a central annular region of the interface between said tapered surfaces under high pressure sufficient to expand said outer member and contract said inner member in said central region while the fluid is confined in said central region by engagement of said tapered surfaces in annular sealing regions of the interface at opposite ends of said central region said injection means including piston means exposed to said fluid under high pressure for holding said injection means against said outer member around said port to prevent leakage; and
- (f) actuating means for axially moving said movable set of jaws toward and away from the other in making up and breaking said joint, respectively.

12. An apparatus for making up or breaking a high-strength, friction-type joint which is adapted to interconnect elongated elements, such as tubings or rods, in end-to-end relation to form a string of such elements, and which includes an outer tubular member and an inner member respectively having complementary, inner and outer tapered surfaces pressurally interengageable along an interface therebetween, said outer tubular member having a port therethrough opening on said inner tapered surface

approximately at the axial midpoint thereof, and one of said members being an end portion of one of said elongated elements, including:

- (a) injection means engageable with said outer member around said port therein for injecting a fluid through said port into a central annular region of the interface between said tapered surfaces under high pressure sufficient to expand said outer member and contract said inner member in said central region while the fluid is confined in said central region by engagement of said tapered surfaces in annular sealing regions of the interface at opposite ends of said central region;
- (b) said injection means including piston means exposed to said fluid under high pressure for holding said injection means against said outer member around said port to prevent leakage; and
- (c) means, including elements engageable with said string on opposite sides of said joint, for relatively moving said members toward each other to maintain said tapered surfaces in engagement in said sealing regions in making up said joint.

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CHARLIE T. MOON, *Primary Examiner.*

U.S. Cl. X.R.

29—238, 525, 237, 252; 285—18

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,451,119

June 24, 1969

Clarence J. Coberly et al.

It is certified that error appears in the above identified
patent and that said Letters Patent are hereby corrected as
shown below:

Column 2, line 4, cancel "may be"; line 65, "unsetting" should read -- upsetting --. Column 18, lines 14 and 15, cancel "as shown in 160"; line 63, "220" should read -- 20 --. Column 19, line 7, "within" should read -- with --; line 28, "means." should read -- means, --. Column 21, line 34, "point" should read -- joint --; line 66, "and" should read -- the --. Column 24, in the table, second column, line 4 thereof, "1,380" should read -- 1.380 --; same table, second column, line 5 thereof, "1,610" should read -- 1.610 --; same table, third column, line 5 thereof, "1,900" should read -- 1.900 --. Column 26, line 53, "end" should read -- ends --.

Signed and sealed this 28th day of April 1970.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents