July 18, 1961 A. G. BODINE 2,992,613

SONIC WELL PUMP TUBING STRING

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Fig. 1

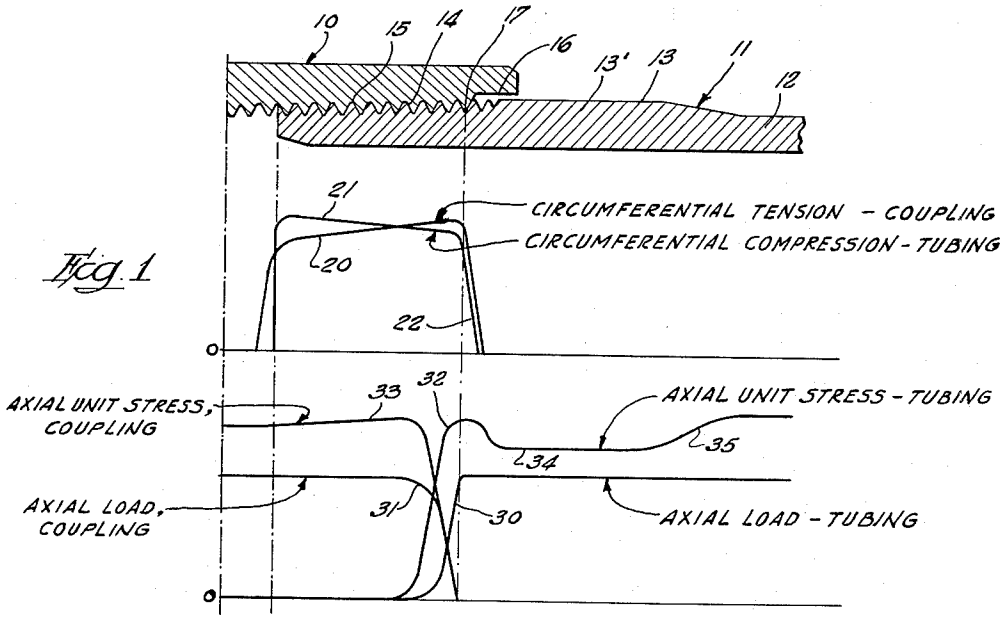
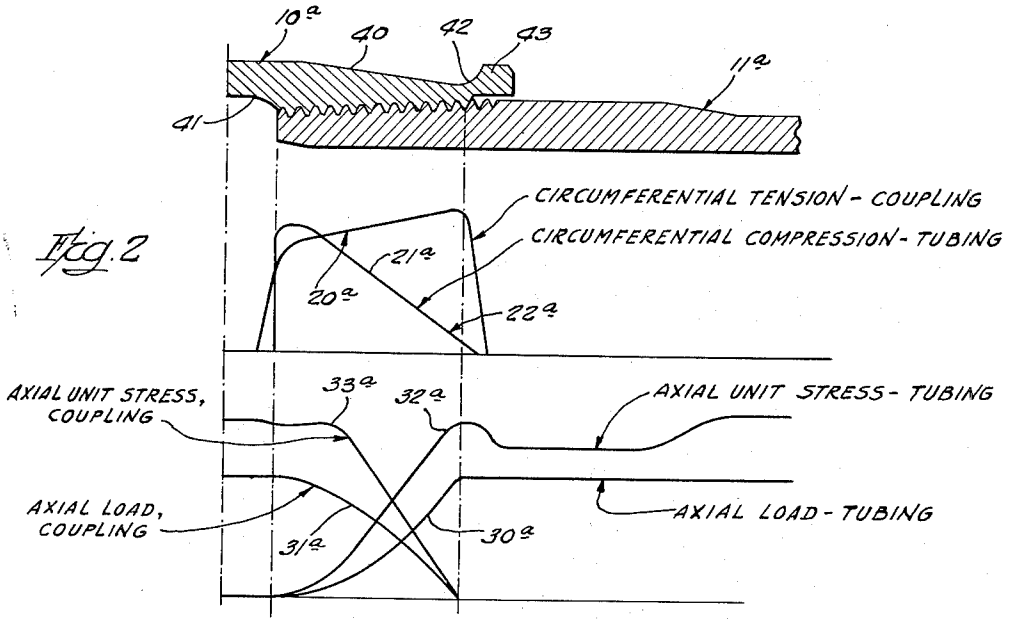


Fig. 2



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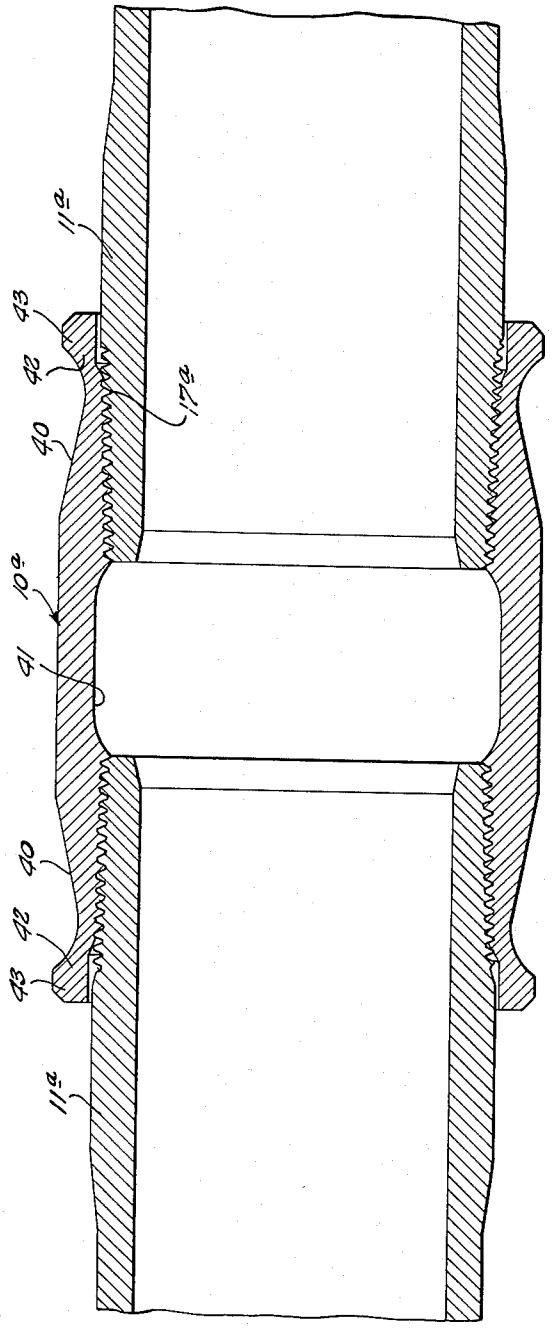


Fig. 3

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Fig. 4

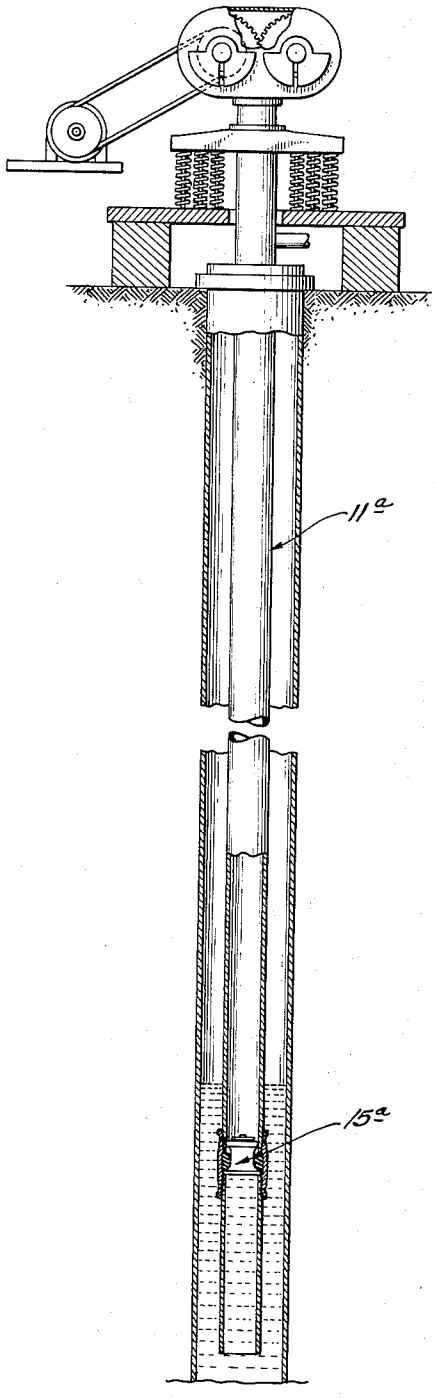
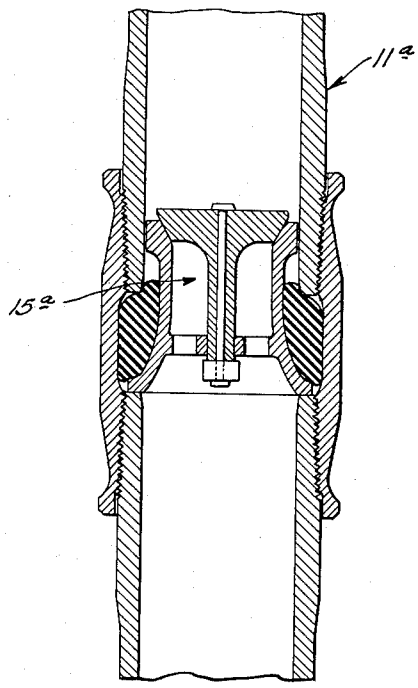


Fig. 5



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United States Patent Office 2,992,613 Patented July 18, 1961

2,992,613

SONIC WELL PUMP TUBING STRING

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2 Claims. (Cl. 103—1)

This invention relates generally to sonic deep well pumps of the general class first disclosed in my issued Patent No. 2,444,912, and more particularly to tubing couplings for such pumps.

This application is a continuation-in-part of my application Serial No. 627,457, filed December 10, 1956, now abandoned.

A sonic pump such as here contemplated operates by virtue of acoustic waves, i.e., periodic elastic deformation waves of tension and compression, transmitted down the pump tubing from a wave generator at ground level to a succession of valves located at various depths within the tubing. The tubing employed is, of course, of elastic material, so as to transmit such waves, and is made up in usual lengths connected by couplings. These couplings comprise sleeves or collars, internally taper threaded at each end, to receive the taper threaded ends of the tubing.

As these couplings are conventionally made, there exist certain relatively large and sharp changes or discontinuities in both axial and circumferential unit stress within the coupling sleeve and tubing at certain locations therein, and these have two adverse effects; first, a change or discontinuity in elastic wave transmission, causing very material wave reflections and consequent loss of wave energy transmission; and second, early acoustic fatigue failure of the tubing, and sometimes of the coupling sleeve. With respect to tubing and coupling failure, it must be understood that the coupling is subject to high frequency cyclic stress reversals or variations in the operation of the wave transmission pump, and should hence be constructed to be strong against such cyclic fatigue failure. However, as actually constructed, the last or outside thread engaged is in a region where the conventional coupling sleeve has relatively great wall thickness, causing high circumferential compressive stress and high radial shear in the tubing, which stress drops to zero just in back of this last thread. Axial unit stress also changes precipitously in both the tubing and coupling sleeve in the region of the last thread engaged. This combination of sharp stress discontinuity creates a weakness at which fatigue failure is likely to occur under the condition of acoustic wave transmission. It is also the sharp stress discontinuity in the region of this last thread engaged that is responsible for the very harmful acoustic wave reflection propensity mentioned above.

One object of the invention is accordingly the provision of a tubing coupling for sonic wave transmission which materially reduces or avoids sharp stress changes or reflective discontinuities along the elastic wave path through the coupling, and a further object is the provision of a tubing coupling for a sonic well tubing whose elastic modulus does not depart, either sharply at any given point in the elastic wave path, or to any material extent, from the modulus of elastic tubing itself.

A still further object is the provision of a coupling for a sonic well tubing which avoids imposition of high compressive stress and radial shear in the tubing at the point of the last thread engaged, and which thereby avoids a weakness point for acoustic fatigue failure.

The invention may best be understood in connection with the accompanying drawings, to which reference is made in the ensuing detailed description, and in which drawings:

FIG. 1 is a diagram of a conventional tubing coupling together with certain stress and load curves;

FIG. 2 shows a similar diagram and curves of the tubing coupling of the invention;

FIG. 3 is a longitudinal sectional view through a preferred embodiment of coupling according to the invention;

FIG. 4 is a longitudinal sectional view of sonic pump tubing incorporating a sonic tubing string and tubing coupling in accordance with the invention; and

FIG. 5 is an enlarged fragmentary section taken from FIG. 4.

In FIG. 1 is shown one-half of a conventional tubing coupling **10**, and an end portion of a conventional upset-end tubing **11** screwed thereinto, with accompanying circumferential and axial stress and load diagrams. The tubing **11** has cylindrical side wall **12**, enlarged or upset end portion **13**, and conventional exterior taper threads **14**. Coupling **10** comprises a sleeve having corresponding internal taper threads **15**, and a thread relief **16** at the end. The "last thread engaged" is indicated at **17**.

It will be understood that the members are screwed tightly together, and that the taper threads elastically expand the coupling sleeve to an extent, while the threaded end portion of the tubing is elastically compressed to an extent. The relative extents of such elastic deformations depend upon the relative wall thickness at different cross sections along the joint. The resulting circumferential tension in the particular coupling sleeve shown for points therealong is represented by curve **20**, and the resulting circumferential compression in the tubing is represented by curve **21**. Owing to the substantial wall thickness of coupling **10** at the "last thread engaged" **17**, the compression in the tubing is high at that point, and drops sharply to zero just outside this thread, as shown at **22**. The two curves **20** and **21** have broad tops of opposite slopes owing to the reverse tapers, and the particular point to be observed is that the stress in the tubing is at a near maximum at last thread **17**, and then drops sharply to zero, as earlier mentioned. It is within the region of this sharp stress drop-off, from near maximum to zero, that the tubing is most prone to cause elastic wave reflections, and also to give way in sonic pumping service by acoustic fatigue failure.

The total axial loads in the tubing and coupling sleeve are represented by curves **30** and **31**, respectively. Because of the substantial thickness of the coupling sleeve out to the last thread **17** engaged with the tubing, this sleeve is elastically quite stiff, and most of the loading is transferred from the tubing to the coupling sleeve within the last few threads of the latter. The load curves **30** and **31** thus drop sharply from full load to zero within the length of these last few threads, crossing one another as shown. Curves **32** and **33**, representing the unit axial elastic stresses in the tubing and coupling sleeve, respectively, similarly drop sharply, within the length of the last few threads, from a high value to zero, also crossing one another, as shown. The drop **34** in curve **32** results from the thick unthreaded section **13**, and the rise at **35** results from the taper between the upset end and the thinner wall **12**. The slope of the top part of the curve **33** is owing to the taper of the coupling sleeve.

These curves thus show that the tubing is subjected to a sharp discontinuity of circumferential compression, from maximum to zero, at the last thread engaged with the coupling; also, that axial stress in both the coupling sleeve and the tubing drops from a high value to zero within the length of a very few threads from the last thread engaged.

The high compressional stress in the tubing at last thread **17**, followed immediately by zero compressional

stress just beyond said thread, means also that the tubing is subjected to a high shear stress at thread **17**, followed immediately by complete relief of this shear stress. The shear stress curve, in fact, is of a form similar to the curve **20**.

The total stress in the tubing at any point is the resultant of components of compressional, shear, and axial stresses, and it will be seen from the curves that the resultant of these stresses is maximized in the region of the last thread **17**, while all these stresses fall to zero within a very short distance. This creates a weakness in the region of the tubing at the "last thread engaged," which may result in early failure by acoustic fatigue under the cyclic axial stress changes continuously imposed during operation of the pump.

Of even greater moment is the fact that the sharp stress discontinuities described, both circumferential, as represented by the leg **22** of curve **21**, and axial, as represented by the steep, crossing portions of curves **32** and **33**, create steep, sharp changes in acoustic wave transmission properties when the tubing is in service in a sonic pump installation. Very material wave reflections occur at these discontinuities, with corresponding loss in wave energy transmission. At each such sharp stress discontinuity in the acoustic wave path down the pump tubing, a loss in wave energy is suffered. In another manner of speaking, the wave decrement at each tubing coupling is quite large, and under such conditions, insufficient wave energy can be transmitted down a sonic pump tubing for good pumping action in the lower regions of a deep sonic pump. This condition prevails before the tubing fails by acoustic fatigue, as explained above, and prevails even if the tubing in a given installation does not suffer failure by such fatigue. Of course, for any given installation, with any specific design of tubing coupling, the acoustic waves sent down the tubing can be held to a "safe" amplitude, at which long tubing life can be predicted. This is one solution for the problem of tubing failure, though, of course, not a desirable one, since it means limitation of power, and a consequent limitation on production volume. No similar solution is available, however, for the problem of wave decrement (reflection losses at each coupling), since each coupling imposing a change in stress concentration acts to choke the flow of available acoustic wave energy down the tubing. Thus, even though the sonic pump be operated under conditions such that tubing failure is no longer a hazard, fractional wave energy loss at each coupling is still present.

FIG. 2 is a diagram similar to that of FIG. 1, but showing the improved coupling of the present invention, and the improved stress distribution gained thereby. The improved coupling sleeve is indicated at **10***a* (see also FIG. 3, showing a longitudinal section of the complete coupling of the invention), and at **11***a* is indicated the end portion of a conventional upset-end tubing, like that shown in FIG. 1. Portions of tubing **11***a* corresponding to tubing **11** are indicated by the same reference numerals, but with addition of the suffix "*a*."

Coupling sleeve **11***a* has as its essential modification a substantial exterior taper, such as indicated at **40**, typically of the order of 10–12°, along its taper threaded region. It also preferably has a central thread relief, as at **41**. Beyond its last thread **17***a*, at the end of the taper **40**, it preferably has a faired or streamlined flare **42** terminating in an enlarged ring section or annulus **43**, whose inside diameter is substantially greater than the major diameter of the last thread **17***a*, and whose outside diameter may be equal to the maximum outside diameter of the coupling sleeve. This annulus functions as a reinforcement of the coupling during handling and during the occurrence of lateral vibrations incident to the elastic wave transmission, and serves also as a "funnel" mouth to facilitate entering the tubing and thereinto during coupling. It will be readily apparent that the taper **40** progressively reduces the elastic stiffness of the coupling sleeve toward its ends, both circumferentially and axially, both of which reductions in stiffness contribute important improvements in stress distribution and in elastic wave transmission properties.

Curve **21***a* is the new curve of circumferential stress distribution in the tubing. Since the tapered coupling sleeve is progressively less stiff, circumferentially, in the direction toward the last thread **17***a*, the compression which it imposes on the tubing is progressively reduced, and instead of a sharp drop-off, as at **22** in FIG. 1, the fall-off portion **22***a* of compression distribution curve **21***a* tapers from maximum to zero over substantially the full length of the engaged threads between the coupling and tubing. There is thus no stress concentration in the tubing at last thread **17***a*, and no sharp and large reduction in compressive stress and shear in the tubing.

Axial load and unit stress distribution are also made materially more gradual as a consequence of the taper of the coupling, and the resulting progressively diminishing elastic stiffness in the axial direction. Because the coupling is materially less stiff, axially, in its end region, the last few threads engaged no longer monopolize the load. Instead, the end region of the coupling is capable of increased longitudinal elastic elongation and contraction under axial loading cycles of wave transmission, and such capability for elastic elongation is progressively increased from the center towards the ends, i.e., towards and to the last thread **17***a*. As a consequence of this increased and controlled capability for longitudinal elastic deformation, the load transference between the threads of the tubing and coupling occurs substantially throughout the engaged threads therebetween. This is represented by the axial load curves **30***a* and **31***a* of FIG. 2, and the extension of the length of the thread region throughout which the load transference occurs will be apparent from a comparison of curves **30***a* and **31***a* of FIG. 2 with curves **30** and **31** of FIG. 1.

The corresponding axial unit stress distribution curves **32***a* and **33***a* for the tubing and coupling sleeve reveal that the unit axial stress in each now falls from maximum to zero over a much longer length of the engaged threads. Instead of the large and sudden axial stress fall-off, as shown by curves **32** and **33** of FIG. 2, there has been achieved the gently and gradually falling stress decrease curves **32***a* and **33***a* of FIG. 2.

FIGS. 4 and 5 show a typical example of the sonic pump combination which embodies the coupling described above. This pump operates by vibratory impulses applied to fluid impelling and check valve element **15***a* mounted in the tubing string **11***a*. These vibratory impulses are accomplished by transmitting sonic elastic vibration waves down the tubing string **11***a*, so that regions of the tubing are caused to elongate and contract in a vibratory manner. The fluid impelling and check valve means **15***a* are located in the vibratory regions of the tubing string. In this manner fluid is pumped along the tubing string. Said pump is fully described in my Patent Number 2,702,-559.

I have found that the couplings described above are very effective transmitters of the sonic waves. These couplings do not reflect the sound waves, but rather transmit the waves on through efficiently, which is important for long transmission in deep wells.

Two different but related benefits are to be observed. The first of these is the relief of the major part of the compressive stress in the tubing in the region of the last thread engaged, with consequent virtual elimination of the weakness region at that point as regards elastic fatigue from acoustic vibrations. In this connection, the total stress in the tubing at this point is again the resultant of the axial stress component, which is substantially unchanged, and the compressive stress and shear, which are now reduced to a small fraction of their value when using a conventional coupling. The coupled tubing is thus

relieved of the hazard of early acoustic fatigue failure when used in sonic pumping service.

The second and more profound improvement is that, in consequence of the circumferential stress in the tubing, and the axial stress in both tubing and coupling sleeve, all undergoing changes from maximum to minimum over long lengths of the engaged threads, instead of entirely within the region of the last thread engaged, there have been achieved long, gradual stress transitions, which are not prone to wave reflections. In a manner of speaking, there has been provided a streamlined wave transmission path through the coupling. Acoustic wave decrement at each coupling is very greatly reduced. Acoustic wave energy flows smoothly and uninterruptedly down the tubing, without suffering a material fractional loss at each coupling. Materially greater sonic energy can accordingly be transmitted to the lower regions of the sonic pump tubing for any given force impulse at the upper end. Put in still other language, the longitudinal elastic modulus of the coupling has been made to approach closely that of the tubing wall. The final effect is improved efficiency, and improved pumping action within the lower regions of the sonic pump by reason of greater energy delivery thereto. The improved coupling will be seen, therefore, to be of improved strength against acoustic fatigue, and therefore to permit use of higher amplitude wave energy, and also to transmit a materially larger proportion of the acoustic wave energy transmitted thereto, giving both improved efficiency, and a materially higher available wave energy level, particularly in the lower regions of a deep sonic well pump.

I claim:

1. A deep well pump which includes: an oscillatory fluid impelling pumping member adapted for placement in the well, a sonic wave generator located at the ground surface, and an elastic pump tubing string operatively interconnecting said sonic wave generator and said oscillatory fluid impelling pumping member, said elastic tubing string being adapted to transmit elastic deformation waves of compression and tension longitudinally therethrough from said generator to said pumping member, said tubing string comprising at least two lengths of elastic tubing having taper threaded ends, and a coupling sleeve joining adjacent ends of said tubing lengths, the two opposite end portions of said sleeve being internally divergent toward the extremities thereof and taper threaded for reception of the taper threaded end of the tubing lengths, and having also external wall surfaces converging progressively at a substantial angle toward the extremities thereof to points opposite the outermost threads thereof engaged with the threaded ends of the tubing lengths, and to a thickness at said points materially less than the wall thickness of the tubing ends opposite said last threads engaged, all in such manner as to attain long, gradual uniformly progressive stress transitions in the threadedly engaged sleeve and tubing ends, whereby to minimize coupling reflections of elastic deformation waves transmitted along the tubing string and to attain low decrement wave transmission therealong.

2. The subject matter of claim 1, wherein the tapered portions of the coupling sleeve merge, outside said points opposite the outermost threads engaged, with flaring wall portions terminating in end collars of substantial thickness whose inside diameter is greater than the maximum major diameter of the taper threads on said sleeve and tubing ends.

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