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A. G. BODINE, JR
PUMPING APPARATUS

2,553,543

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2 Sheets-Sheet 1

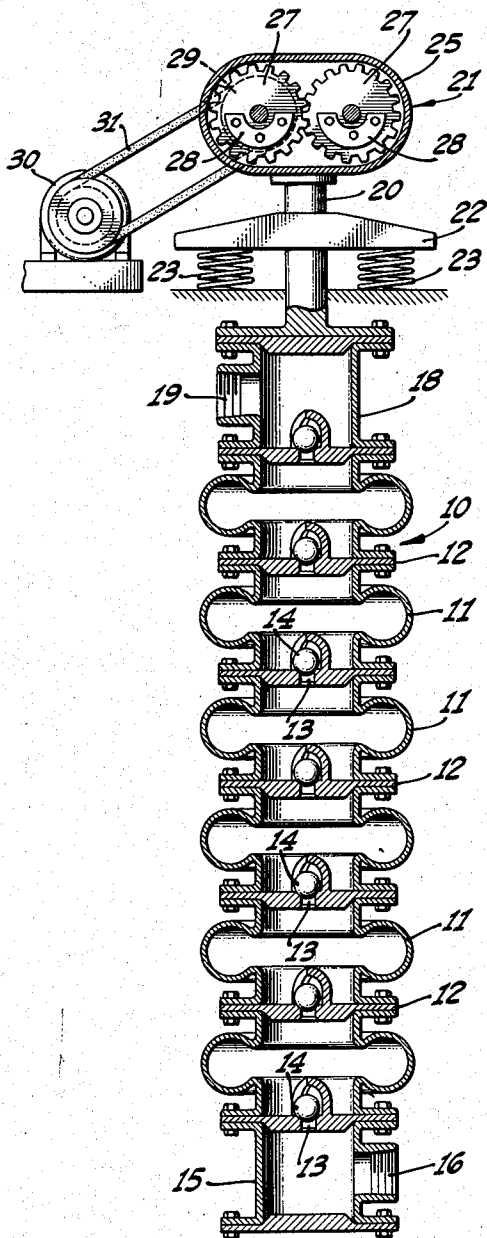


FIG. 1.

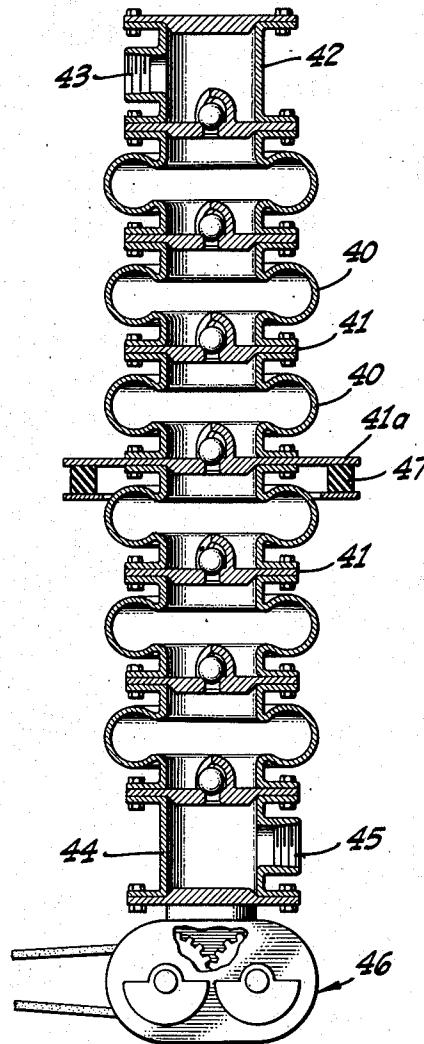


FIG. 2.

INVENTOR
Albert S. Bodine, Jr.

BY *Forrest Hilly*
ATTORNEY.

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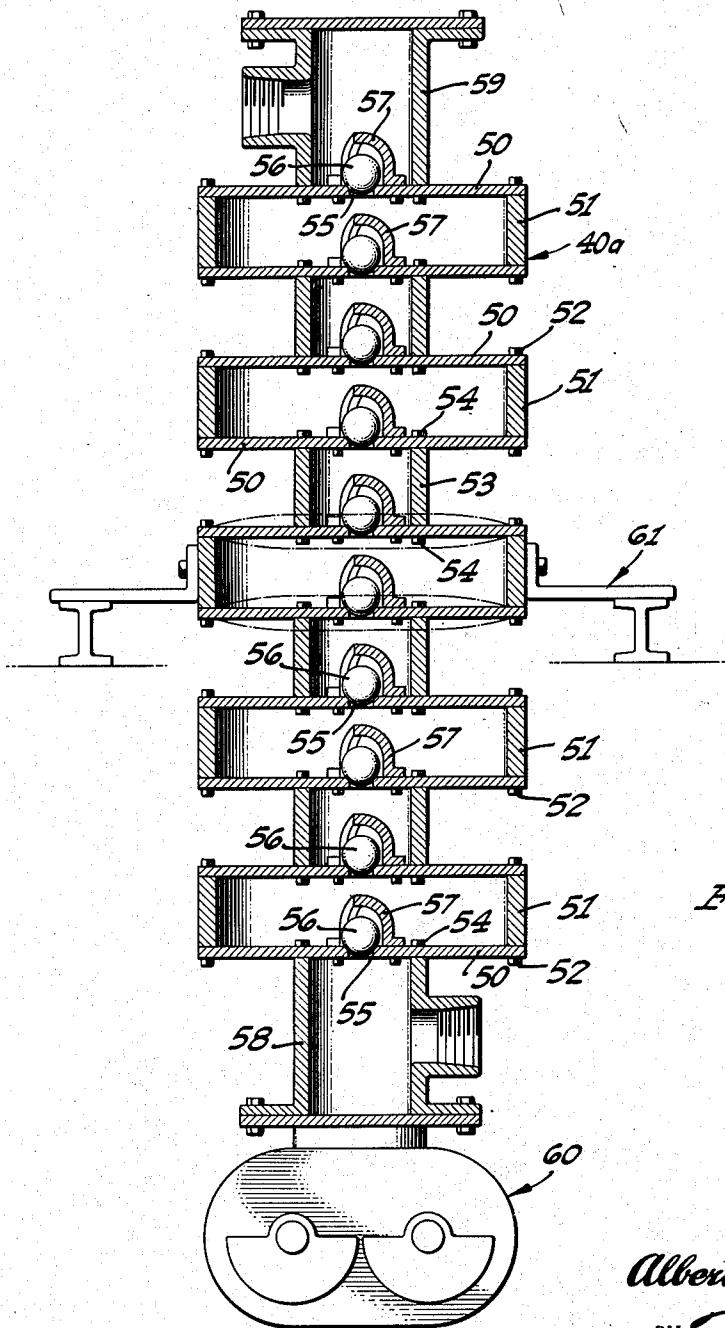


FIG. 3.

INVENTOR
Albert G. Bodine, Jr.
BY *James J. Lilly*
ATTORNEY

UNITED STATES PATENT OFFICE

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PUMPING APPARATUS

Albert G. Bodine, Jr., Van Nuys, Calif.

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11 Claims. (Cl. 103—1)

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This invention relates generally to pumps, and more particularly to pumps operated by periodic longitudinal waves of tension and compression in an elastic tubing.

The present application is a continuation-in-part of my copending, parent application entitled Method and Apparatus for Pumping, Serial No. 761,456, filed July 17, 1947, and allowed October 22, 1947, now Patent No. 2,444,912. In said application I disclosed a type of deep well pump operated by periodic waves of tension and compression generated by means of a sonic vibration generator at the ground surface and transmitted via an elastic column to the pump unit proper at the bottom of the well, this elastic column being typically the steel pump tubing. Among the various embodiments of pump disclosed in said application was a species (more particularly applicable to surface uses than to wells) in which the elastic tubing is folded or circumferentially corrugated in a bellows-like fashion, having the effect of greatly increasing its compliance, or in other words, its amplitude of oscillation under the drive of the waves of tension and compression transmitted to it, and having the further effect of greatly shortening the wave length (along the tubing) of longitudinal waves of compression and tension traversing its length. The primary object of the present invention is the provision of such a pump, with its several attendant advantages and accomplishments. Among the objects, and corresponding accomplishments, is the provision of an efficient, relatively compact, multi-stage, high pressure pump.

The invention will be better understood by referring now to the following detailed description of present illustrative embodiments thereof, reference for this purpose being had to the accompanying drawings, in which:

Figure 1 is a longitudinal medial sectional view, partly in elevation, of a pump embodying the invention;

Figure 2 is a similar view showing a modification; and

Figure 3 is a similar view showing another modification.

In Figure 1, the pumping system includes an elastic column 10 in the form of a fluid conduit made up of a multiplicity of outwardly folded bellows sections or elements 11, each flange-connected to the next, and with intervening plates or walls 12 having central ports 13 controlled by check valve balls 14. To the lower bellows section is connected a box section 15 formed with an inlet 16 to which a flexible intake pipe (not shown)

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may be connected. To the upper bellows section is connected a box section 18 having outlet 19 to which a flexible outflow pipe (not shown) may be connected. Box section 18 is suspended from vertical rod 20 having mounted on its upper end sonic vibration generator 21, presently described in more detail. Rod 20 is carried by transverse plate 22 supported on suitable springs 23, which are in turn supported by any suitable supporting means, as indicated.

The housing 25 of sonic generator 21 contains a means for vertically vibrating the plate 22 on the supporting springs 20, and consequently vertically vibrating the upper end of the bellows-like column 10. The means for generating vibrations contained within housing 25 may be of any type, but illustratively is of a type having meshing oppositely rotating spur gears 27 carrying eccentric weights 28 which balance out horizontal vibrations but are additive to produce a substantial resultant oscillatory force in a vertical direction. The driving pulley 29 of the generator mounted on the shaft for one of the spur gears, is driven by electric motor 30 through belt 31. I refer to the generator as a sonic generator, because the vibration frequency is typically in the sonic range, and also because the vibrations generated thereby travel in the elastic column connected thereto with the speed of a sound wave. Of course, the invention is not necessarily limited to an audible sound frequency.

The oscillating force applied to the upper end of the corrugated tubing 10 by sound wave generator 21 causes the upper end of said tubing to be alternately elevated and lowered through a short displacement distance. This oscillatory movement causes longitudinal deformation waves of tension and compression to be launched down said tubing. These waves travel down the tubing, accompanied by flexure of the bellows sections 11. As the upper end portion of the tubing is moved downwardly by the generator 21, the bellows sections 11 will thus tend to be progressively compressed, or slightly closed, in a wave-like action down the tubing. On the succeeding upstroke, the reverse action occurs, the successive bellows section from top to bottom being slightly expanded, each in its turn, and a wave of expansion thus travels from top to bottom. It should of course be understood that in a strict sense, and considering the individual fibers making up the steel walls of the bellows sections, the stress is not entirely one of compression when the bellows sections are "closed," nor of tension when they are "opened," but rather one of mixed compres-

sion and tension under the bending condition characteristic of each situation. An analysis of the distribution of stress and compression within the walls is however not of particular interest in the present problem. It is sufficient if it is recognized that, considering each bellows section as a whole, and the connected series of bellows sections as an elastic column, alternate waves of "compression" and "tension" will progress longitudinally of the column, and will be reflected by the ends of the column, in a manner generally analogous to the action of longitudinal waves in elastic pipes and rods. For the purpose of the specification and claims, therefore, the terms "compression" and "tension" refer to the column structure as a whole, rather than to the distribution of stress within a given portion of column wall.

Preferably, the vibration generator is driven at such a speed as will resonate the column 10 and establish a standing wave therealong, characterized by the appearance of velocity anti-nodes at the locations of the check-valved members 12. In such operation, the check-valved walls 12 are regions of maximum vertical oscillatory movement, while the bellows sections 11, while constantly undergoing expansive and contractive action, are actually stationary, or substantially so, at their medial transverse sections. The two check valved walls on opposite sides of a given bellows section 11 will move in opposite directions at any given instant, all in accordance with the known principles of longitudinal wave action in resonated columns governing this type of phenomena. While this phenomena is understood by those skilled in the art, it may briefly be explained herein that standing waves result from longitudinal waves in elastic columns when the frequency of such waves is such that a wave transmitted down the elastic column and that reflected upwards from the lower end thereof mutually interfere and cancel one another at certain longitudinally spaced regions to create velocity nodes, while mid-way between said regions, and at the ends of the columns, the transmitted and reflected waves may be additive to effect peak oscillation. In straight columns, the speed of sound is very high, thus causing long wave lengths, and since the velocity nodes are one-half wave length apart, the valve spacing is of considerable length; in the folded construction characteristic of the invention, however, the internodal spacing may be very substantially less because of the reduced speed of sound in the more compliant structure.

Considering now the lowermost check valved wall 12, it should be understood that this wall will oscillate in a vertical direction as the result of longitudinal wave action transmitted to it via the corrugated column 11 from the vibration generator 21. On each downstroke of said lowermost wall 12, fluid displaced thereby will be forced upwardly through the passageway 13 and past the check valve ball 14, which will at such time be unseated, as its acceleration in a downward direction owing to gravity will be less than that of the wall 12 driven by the wave action in the column 10. On the succeeding upstroke of the lowermost wall 12, valve ball 14 will seat, causing the column of liquid thereabove to be elevated. Referring again to the downstroke of the wall 12, it should be evident that during such downstroke, a void will be created in the bellows section 11 immediately above, and the resulting

suction aids in drawing the fluid up through the passageway 13.

While the pump is operative without the use of the additional check valves above the lowermost one already described, and will operate to elevate a column of fluid through the apparatus to be delivered via the outlet 19, higher delivery pressures and additional pumping efficiency are gained by the use of the additional valves. As already explained, each check valved wall 12 above the lowermost one will operate with movement opposed to the check valved plate immediately below it. Thus, for example, the check valved wall 12 which is second from the bottom will be traveling downwardly during the upward travel of the lowermost such wall, and the check valve of the second wall is thus open to receive or pass the fluid column being elevated at such time by the lowermost wall 12. And on the upstroke of the second wall 12 from the bottom, the lowermost wall 12 is descending, with the result that the second wall 12 from the bottom adds to the suction that is effective to elevate well fluid through the passageway 13 in the lower wall 12. This action is repeated throughout the length of the multi-stage pump, and permits the development of relatively high delivery pressures.

It is not entirely essential that the resonant operation be established, as pumping will occur even without the resonance. However, maximum oscillatory displacement of the check valved wall 12 occurs with resonant operation, and is accordingly preferred. As already described, such operation is characterized by the establishment of velocity anti-nodes (regions of maximum vertical displacement) at the locations of the several check valved walls 12, with intervening velocity nodes (regions of minimum vertical oscillations) at the bellows sections midway between the check valves. To accomplish such operation, the speed of the vibration generator 21 is adjusted until the described resonant, standing wave action is observed. Such speed will depend upon the dimensions, stiffness or compliance and mass of the oscillating apparatus, and cannot be predicted in advance in absence of a relatively complex mathematical treatment. If the tubing sections were straight rather than formed as bellows sections, the check valved walls 12, based upon the velocity of purely compressional waves, would be one-half wave length apart at the critical speed of the generator 21 for resonant operation. However, with the folded or bellows-like formation of the invention, the half-wave spacing distance between successive walls 12 for resonant operation is much less than the straight pipe half wave length, so that a relatively compact apparatus is achieved.

Figure 2 shows an embodiment having an elastic column made up of a plurality of bellows sections 40 and intervening check-valved plates or walls 41, just like the corresponding components of the embodiment of Figure 1. In addition, the elastic column formed of said components 40 and 41 has a box member 42 at the top provided with outlet 43 for connection to a flexible delivery pipe, and has at the bottom a box section 44 formed with intake pipe 45 adapted for connection with a flexible intake pipe. The vibration generator 46 is in this case suspended from the lower end of the column, being connected directly to intake box section 44. This vibration generator 46 may again be of any suitable type capable of delivering the vibrations to the elastic column in a direction longitudinally

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of said column. In this instance, the pump is supported near the midsection of the column by laterally extending one of the check valved plates, such as 41a, and supporting it on resilient vibration insulating mounting 47.

The embodiment of Figure 2 operates according to the same essential principles as does that of Figure 1. The sonic generator 46 imparts vertical oscillations to the lower end of the elastic column, causing successive deformation waves of tension and compression to be transmitted from bellows section to bellows section up the column. By adjusting the speed of the generator to resonate the column, the check valved walls 41, including the intermediate mounting plate 41a, are located at velocity anti-nodes, and hence oscillate vertically, the velocity nodes being located midway between the plates 41, i. e., at the mid-sections of the bellows members. The bellows sections flex to transmit the wave action just as in Figure 1, the only difference being that the wave action is initially launched up the column instead of down the column. The support 47 for the column might be located at any convenient velocity node or anti-node instead of the particular velocity anti-node coinciding with the mid-section of the column.

Figure 3 shows a modification of Figure 2, wherein the elastic bellows sections are made up of simple structural forms. In Figure 3, each elastic bellows section 40a includes two spaced flexible walls or diaphragms 50, whose rim portions are connected to opposite ends of a side wall ring 51 by suitable cap screws 52, as shown. Each such bellows assembly is connected to the next by a smaller side wall ring 53 by means of cap screws 54. The portion of each wall 50 between outer and inner connecting rings 51 and 53 is capable of a diaphragm-like elastic deflection.

The center of each wall 50 is formed with a valve port 55 for a check valve ball 56, and suitable ball cages 57 are attached to the walls 50.

The elastic column as thus described may have intake and discharge sections 58 and 59, similar to the corresponding members of Figure 2, as well as an elastic wave generator 60 of the type disclosed in detail in Figure 1. Suitable mounting means for the pump is indicated at 61, engaging one of the central connecting rings 51.

The operation of the pump of Figure 3 will be understood to be the same as that of Figure 2 in all respects, the only difference being in the specific construction of the bellows sections, which in the case of Figure 3 have their entire compliant or elastic area in the walls 50 between the connecting rings 51 and 53. These walls 50 are capable of an elastic deflection throughout a range as approximately indicated by the dot-dash lines for the center section in Figure 3. The compliant wall structure as thus constituted transmits the wave action in the same general way as the specific bellows formations earlier described. It will of course be evident that the type of bellows formation shown in Figure 3 may also be incorporated in a pump of the type shown in Figure 1.

The drawings and description disclose several illustrative embodiments of the invention. Various changes in design, structure and arrangement may however be made without departing from the spirit and scope of the invention as defined by the appended claims.

I claim:

1. A pump of the character described, comprising: a flexible elastic longitudinally com-

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pressible and expansible tubing circumferentially corrugated along its length, an inlet port opening into one end portion of said tubing, a check-valve controlling said port, a delivery port leading from the other end of the tubing, and a sonic wave generator operatively connected to the corrugated tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally therealong.

2. A pump of the character described, comprising: a flexible elastic longitudinally compressible and expansible tubing circumferentially corrugated along its length, an inlet port opening into one end portion of said tubing, a delivery port leading from the other end of the tubing, a series of check valved parts in longitudinally spaced positions along the tubing, and a sonic wave generator operatively connected to the corrugated tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally therealong.

3. A pump of the character described comprising: an elastic tubing embodying flexible elastic wall means forming a series of interconnected outwardly folded compressible and expansible elastic bellows sections, inlet and outlet ports at opposite ends of the tubing, a fluid displacing wall closing the tubing at the inlet port end thereof, a fluid passage through said wall, a check-valve controlling said passage, and a sonic wave generator operatively connected to an end of said tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally through and along the elastic outwardly folded walls of the bellows sections to alternately compress and expand said sections.

4. A pump of the character described comprising: a flexible elastic tubing embodying a series of interconnected elastic compressible and expansible bellows assemblies, said assemblies including transverse partition walls separating the assemblies from one another, check-valved fluid ports extending through said partition walls, inlet and outlet ports at opposite ends of said tubing, and a sonic wave generator operatively connected to said tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally therealong.

5. A pump as defined in claim 4, wherein said bellows assemblies each comprise a pair of spaced transverse elastic walls, together with side wall means connecting the marginal portions of said walls, said spaced walls forming the said check valved partition walls, and wherein each bellows assembly is connected to the next by a side wall means engaging said elastic bellows walls at a spacing inside said first mentioned side wall means.

6. A pump of the character described comprising: a flexible elastic tubing embodying flexible elastic wall means forming a series of intercommunicating elastically compressible and expansible bellows sections, an inlet port opening into one end portion of said tubing, a check-valve controlling said port, a delivery port leading from the other end of the tubing, and a sonic wave generator operatively connected to the tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally through and along the walls of the successive bellows sections constituting the tubing.

7. A pump of the character described comprising: a flexible elastic tubing embodying flexible elastic wall means forming a series of intercommunicating elastically compressible and expan-

sible bellows sections, an inlet port opening into one end portion of said tubing, a check-valve controlling said port, a delivery port leading from the other end of the tubing, a sonic wave generator operatively connected to the tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally through and along the wall of the successive bellows sections constituting the tubing, and a resilient supporting means for said tubing adapted to accommodate the longitudinal wave action of the tubing.

8. A pump of the character described comprising: a flexible elastic tubing embodying flexible elastic wall means forming a series of elastically compressible and expansible bellows sections, transverse partition walls intervening therebetween said bellows sections, check-valved fluid ports extending through said walls, inlet and outlet ports at opposite ends of said tubing, and a sonic wave generator operatively connected to an end of said tubing and adapted to continuously transmit alternate waves of compression and tension longitudinally through and along the walls of the successive bellows sections constituting the tubing.

9. A pump of the character described comprising: an elastic pump tubing embodying a series of interconnected compressive and expansive bellows elements, each of said bellows elements including flexible elastic wall means capable of alternate deformations in reverse directions longitudinally of the tubing in response to alternate

waves of compression and tension transmitted along the tubing, inlet and outlet ports at opposite ends of the tubing, and a sonic wave generator operatively connected to the tubing and adapted to transmit alternate waves of compression and tension longitudinally along said tubing.

10. A pump according to claim 9, including resilient means supporting the tubing in a vertically disposed position, and wherein the sonic wave generator is mounted on the upper end of the tubing.

11. A pump according to claim 9, including resilient means supporting the tubing in a vertically disposed position, and wherein the sonic wave generator is suspended from the lower end of the tubing.

ALBERT G. BODINE, JR.

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