

Feb. 1, 1938.

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2,107,151

LOAD COMPENSATION IN OIL WELL PUMPS

Filed Oct. 17, 1934

2 Sheets-Sheet 1

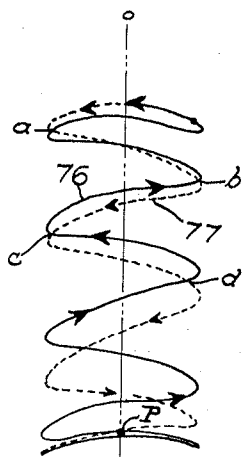
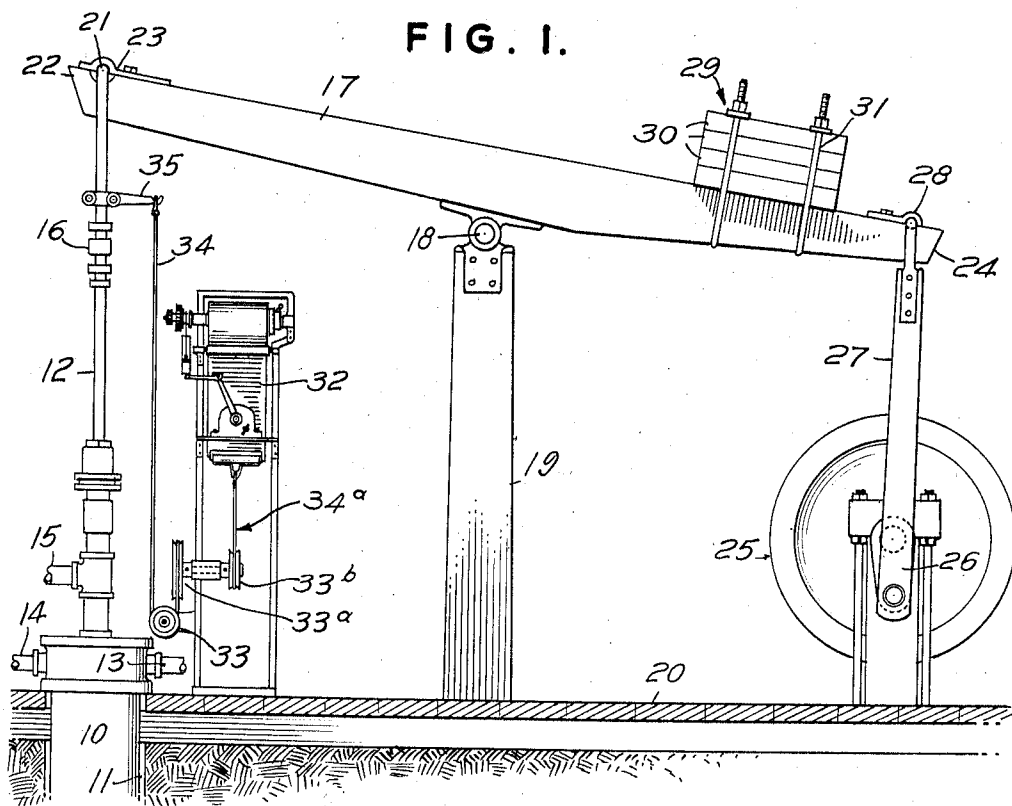


FIG. 6.

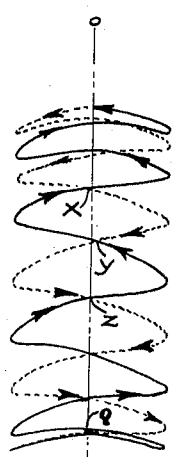
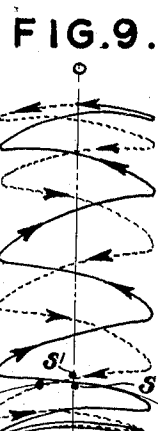
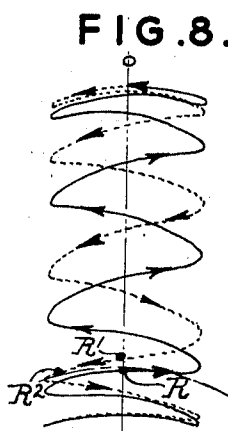


FIG. 7.



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2 Sheets-Sheet 2

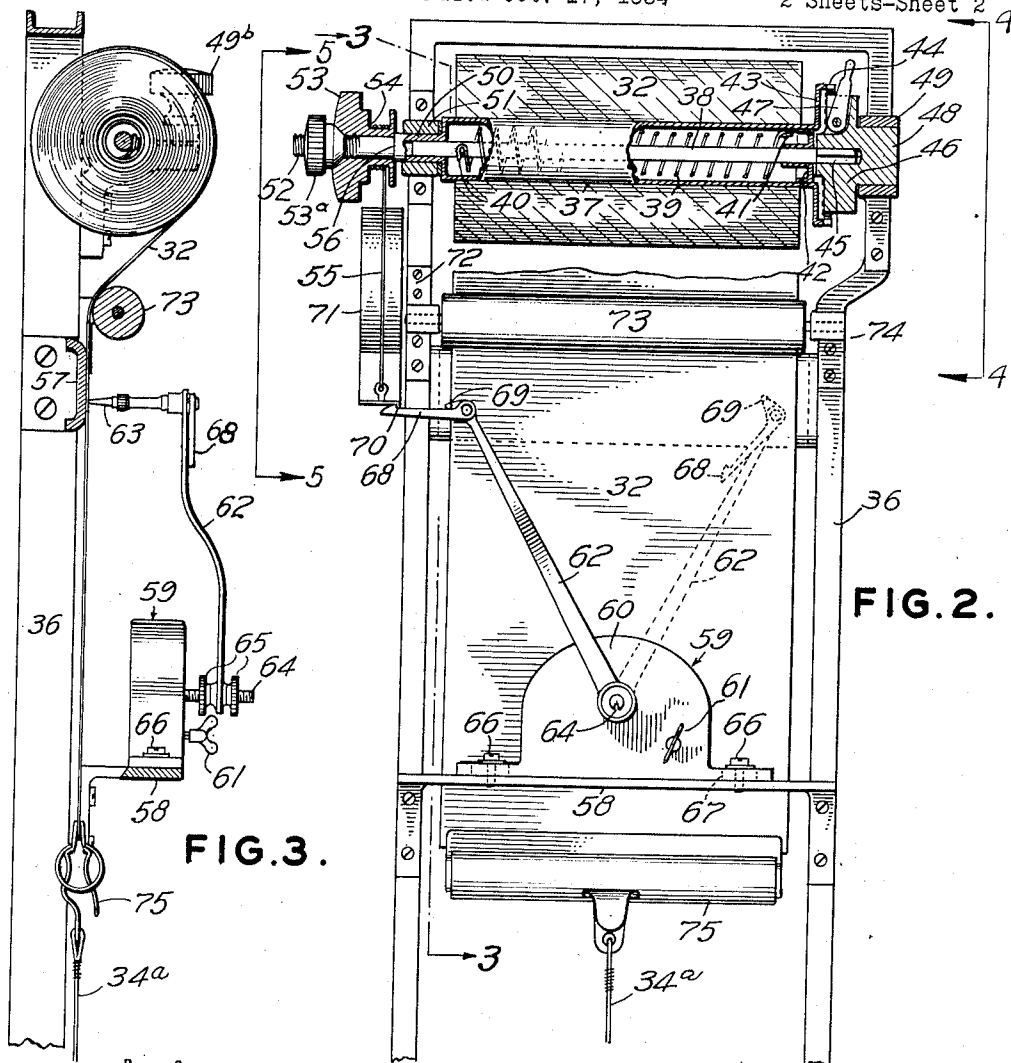


FIG. 2.

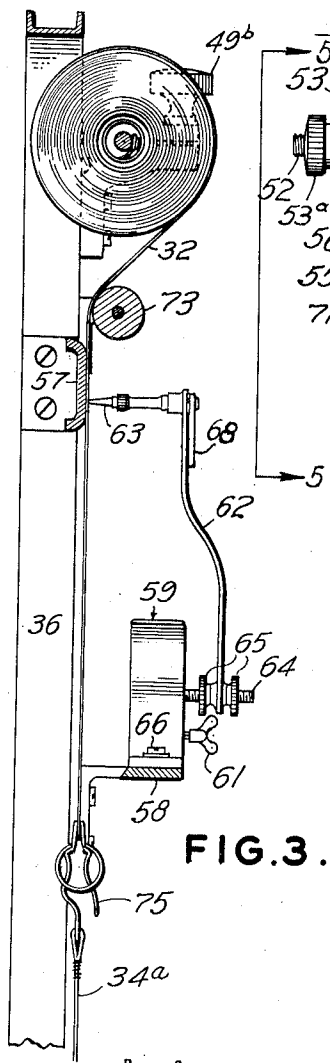


FIG. 3.

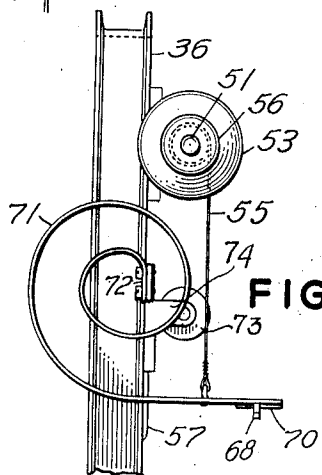


FIG. 5.

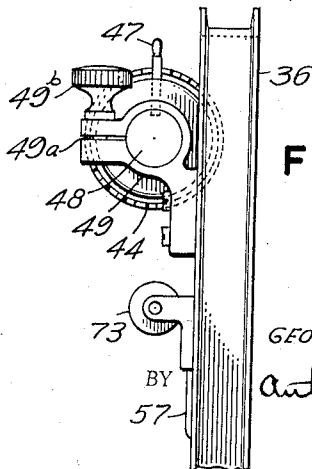


FIG. 4.

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LOAD COMPENSATION IN OIL WELL PUMPS

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9 Claims. (Cl. 234—29)

This invention relates to load compensation in the operation of reciprocating type of machinery, and more particularly it relates to load compensation to be effected in the reciprocating cycle of deep-well oil pumps.

The invention can therefore be said to revolve around the problem of detecting, appraising and correcting unbalanced forces, or load differences, or unbalanced load conditions such as may exist relatively between the upstroke and the downstroke, respectively, of what is known as the plunger rod or sucker rod in oil-well pumps or the like.

Conventional oil well pumps have an axially and vertically moving plunger-rod composed of numerous sections and which extends down the oil well, and which is usually actuated to perform its up and down movement by a double-armed rocking lever or "walking beam". The pump-rod is attached to one end of the beam, the opposite end of which may be crank-driven by a suitable prime mover or motor.

One difficulty encountered in the operation of such pumps is due to the largely uneven load distribution between the upward stroke and the downstroke of the pump rod. The heavy load on the upstroke is caused not only by the head against which the pump must work, but also quite signally by the weight of the long plunger-rod which must be lifted on the upstroke. This inequality must be counter-balanced as much as possible if the machine is to be protected from undue and perhaps injurious strains and stresses, and it has therefore been the practice to attach an appropriate counter-weight to the driving end of the rocking lever so as to equalize these conditions to a certain degree of satisfaction, and to avoid certain peak loads in the driving mechanism.

However, the exact and proper amount of counter-balance is not always easy to determine in the field. Especially when the pump works under changing conditions of depth which makes necessary the lengthening of the plunger-rod and increasing the head, this means a tendency of throwing the machine out of balance, which should be met by proper weight compensation. Such correction, however, is more or less a case of hit and try, and when neglected by the operator, or difficult to carry out, may cause excessive and unnecessary wear on the machinery and concurrent therewith an unnecessarily high power consumption. Such conditions and losses have been known to maintain for a long time unnoticed or neglected to the detriment of the plant.

Other sources of faulty or unbalanced pump operation may be found in improper functioning of the pump valves, faulty plunger operation, binding of parts, and other defects of a mechanical or operative nature.

One object of this invention is to devise a performance-exhibiting apparatus or arrangement associated or associable with oil well pumps, which makes it possible to determine and correct faults in the operation of the pump, and to take steps to effect load balance to the end of obtaining maximum mechanical efficiency, reducing to a minimum wear and tear and power consumption, and effecting smooth operation of the pump machinery.

Other objects are to provide a simple device or arrangement of devices with the aid of which the degree and character of a desired correction such as a required amount of weight balance for load compensation can be determined, and a balanced condition be obtained; also to devise a recording system by means of which load charts are produced which can be readily interpreted with a high degree of accuracy, and especially with respect to load balance.

Therefore, in order to attain these ends, an embodiment of this invention comprises a performance-exhibiting apparatus arrangement, which is associated or associable with machines of the reciprocating type, and more particularly with machines of the slow-moving type, such as oil well pumps, in which speed changes are substantially corresponding and proportionate to load changes. In other words, the apparatus herein contemplated to embody the invention, permits using speed characteristics in the operating cycle of the plunger rod as criteria of the load characteristics or of the load differences as may exist between the up stroke and the down stroke of the pump.

The invention proposes to utilize changes observed in the speed of the plunger rod during a pumping or reciprocating cycle for the purpose of recording, as in a diagram, the load conditions prevailing in the cycle. In this way abnormal speed indications are used as criteria for uneven balance, or else to render visible such other defects in the operation of the machine or pump which express themselves in abnormal speed conditions.

According to one of its aspects the invention is based upon the observation that an optimum of average power consumption for the operating cycle of the pump along with smooth pump operation are attained when the machine is so balanced

by counterweight adjustment that the time for the up stroke is as nearly as possible the same as the time for the down stroke of the plunger rod.

Consequently, the invention contemplates the devising of means which make possible the determination or recording of the time used for the respective strokes, permitting a comparison of both. The time difference recorded, or obtainable from the record, may then be considered as a criterion for the average load difference and may serve as a measure of the counter-weight correction needed.

That is to say, the invention contemplates timing the movement of the plunger rod or load-carrying reciprocating element during the identical distance of travel for either stroke of the operating cycle, and determining the time difference to serve as a criterion for the average load difference and as a measure of the counterweight correction needed to restore average balance.

As a matter of definition and terminology, it should be noted that the word "timing" should hereinafter be understood to mean the taking or determining or recording of the time interval needed for a length of mechanical movement such as of the pump stroke or a portion thereof. The operating cycle of the pump is understood to include two consecutive strokes, that is, more specifically the up stroke and the down stroke.

According to one feature, the counterweight upon the rocking lever is adjusted until the speed conditions for the plunger-rod are substantially equal for the upward as well as for the down stroke. A speed diagram is drawn by having a strip of recording paper move in proportion to the speed of the plunger-rod, while a pencil moves at a suitable fixed rate transversely of the path of the paper. The curve or line thus produced reflects the change of speed during a pump stroke. By comparing a curve produced by the upstroke with one created by the down stroke, a conclusion may be drawn as to whether a correction is needed, as well as to the amount of correction necessary.

According to another feature, an oscillating recording member charts a series of oscillations of a certain frequency upon a recording surface which moves substantially in unison with, or in proportion to, the plunger rod and in a direction transversely to the oscillating movement of the recording member. The number of oscillations which may include fractions thereof, thus recorded during the movement of the plunger rod, permit to compensate accurately the length of time, providing the frequency of oscillations be known. Such a chart or graph recorded by the up stroke may be compared with one taken from the down stroke of the pump, in order to determine whether and what amount of difference exists in the respective lengths of time it takes the plunger rod to travel up and down respectively a fixed distance such as the length of the operating stroke or a portion thereof.

Another feature employs a convenient method of producing a curve which makes clearly visible the speed or load changes in a pump stroke or cycle, by the use of an oscillator or oscillograph. This oscillator may be in the form of the well known "Metronome" whose pendulum oscillates at a suitable adjusted steady frequency across the moving record-strip. The pendulum according to this invention is provided with a writing point which by its relative movement upon the record strip describes a characteristic zig zag or

undulating line from which operating conditions can be readily interpreted.

According to still another feature the oscillating curve or undulating line representing the relative speed of the upstroke is superimposed upon a similar curve created by the down stroke. This furnishes a closed curve or diagram for the entire amplitude or pumping cycle, permitting the direct comparison between upward stroke and down stroke and an immediate evaluation of the diagram in terms of counter-weight correction. More specifically, if the closed diagram is properly taken with all working parts properly adjusted and coordinated and the zero phase of the pendulum be timed to coincide with the zero phase of dead-center position of the plunger rod; the curves fluctuate about the same zero line in such a way that the phase of one curve is shifted by 180° against the phase of the other curve. Therefore, after a required weight correction shall have been made, both curves in an ideal case of balanced condition will have characteristic points of intersection located directly upon or close to the zero line. If, however, the machine is improperly balanced these points of intersection fall more or less off the zero line, and the degree of such deviation may be considered as a rough indication or gauge for the amount of counter-weight correction needed for the restoration of a balanced working condition.

In the preferred embodiment of this invention the recording strip moves up and down in correspondence with the up and down movement of the plunger-rod. The movement of the record strip is proportional to, and directly controlled from the movement of the plunger-rod, through suitable transmitting elements such as a pulling string run over a system of rollers or pulleys. Movement of the plunger-rod in one direction unrolls the strip from a reel preferably against the tension of a spring connected with the reel, while movement of the plunger-rod in the opposite direction allows the spring to rewind the recording strip upon the reel. The pendulum of a metronome or similar oscillating instrument is provided with a recording point, and this instrument placed into writing relationship with the recording paper strip. Preferably the metronome is bodily adjustable to and fro with respect to the recording strip and also laterally in order to establish correct writing and recording relationship. An automatic trip arrangement can be adjusted to synchronize the recording with a desired phase of the pump stroke.

In the preferred embodiment the metronome may also be adjustable in other directions, for instance laterally, for reasons of timing the swing of the metronome with respect to the turning point of the pump stroke, to help establishing curves of desirable symmetry with regard to the zero line. It is of course also possible to adjust the frequency of the pendulum in the metronome to the end of establishing desirable diagram characteristics.

Also, in the preferred embodiment provision is made to increase the ratio of speed through the connection from the pump-rod to the recording strip. This will cause an appreciable relative increase of average speed in the movement of the record strip. In particular, it will effect a noticeable stretching in the middle portion of the diagram so as to make its reading and graphic evaluation easier and more accurate. The middle portion of the diagram furnishes a more suitable

criterion than the end portions which latter consist of more narrowly crowded zig zag lines as they approach the turning or dead center point of the pump stroke.

5 It is to be noted that novelty lies in the apparatus arrangement proper of this invention, inasmuch as it lends itself to a variety of purposes and applications, and with regard to conditions where not only the relative value but the absolute
10 value of the diagram indications is to be used for specific determinations. In other words, the principle embodied in the apparatus herein disclosed, of charting oscillations of a fixed frequency upon a moving recording surface, may
15 be applied as well for an accurate determination of the speed of any reciprocating motion, as will hereinafter be explained more clearly. This may also be considered as a method and means for measuring time intervals on the basis of a suitable
20 unit of time for the purpose of timing the length of a mechanical movement.

An embodiment of such principle of time measurement in one of its simplest forms may be said to include a relatively stationary time-marking
25 element and a recording surface moving in substantially rectilinear direction, the co-operative relationship of the time-marking element and the moving surface being such that consecutive time marks of an adopted unit of time are automatically
30 recorded upon the moving surface, thus defining the length of the movement to be timed in terms of time-unit marks or fractions thereof.

It should be understood that the invention is not confined to the specific embodiment herein
35 disclosed but that suitable modifications and changes are possible to embody the principle of this invention. For instance it should be understood that other than the mechanical means shown, may be employed for the determination or
40 recording in a comparative way of the characteristic speed changes or speed conditions in the operating cycle of the machine.

The invention possesses other objects and features of advantage, some of which with the foregoing will be set forth in the following description. In the following description and in the
45 claims, parts will be identified by specific names for convenience, but they are intended to be as generic in their application to similar parts as the art will permit. In the accompanying drawings there has been illustrated the best embodiment
50 of the invention known to me, but such embodiment is to be regarded as typical only of many possible embodiments, and the invention is not to be limited thereto.

55 The novel features that I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its
60 method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in connection with the accompanying drawings in which—

65 Fig. 1 shows the driving arrangement for a conventional oil well pump with the novel control or recording device diagrammatically shown.

Fig. 2 is a part sectional front view of the recording device proper.

70 Fig. 3 is a sectional side elevation of the recording device taken upon line 3—3 of Fig. 2.

Fig. 4 is a detail view of the recording device taken upon Fig. 2 along line 4—4, to show a clutch arrangement for adjusting the spring tension of the recording reel.

Fig. 5 is a detail view taken along 5—5 upon Fig. 2 to show an automatic trip and start arrangement for the metronome.

Figs. 6 and 7 illustrate unbalanced and balanced operation in the form of theoretical graphs.

Figs. 8 and 9 are graphs similar to Figs 6 and 7 taken in actual operation wherein Fig. 9 shows a degree of balancing accomplished over Fig. 8.

As shown in Fig. 1 an oil well pump in its essentials comprises a vertical pump cylinder 10
10 extending down into the oil well shaft 11. A plunger rod 12 is arranged for reciprocating vertical movement in the pump cylinder 10, and there are provided gas inlets and outlets 13 and 14 respectively and an oil outlet 15. In ordinary
15 practice the plunger rod 12 ordinarily is composed of a series of lengths or sections which are endwise connected or locked together by suitable couplings such as indicated at 16. Consequently the total length of the plunger rod 12 may be
20 altered by either adding or taking away one or a number of sections according to the depth of the oil well.

A drive for this pump comprises a rocking lever or walking beam 17 which is fulcrumed at 18
25 upon a column 19 which rises from an operating platform indicated at 20. The plunger rod 12 is shown to be operatively engaged by its top end portion 21 to one end 22 of the rocking lever, as through bearing member 23.

The opposite end 24 of the rocking lever is connected with a prime mover or motor diagrammatically indicated at 25 and driven thereby
30 through a crank 26 and a connecting rod 27. A bearing connection 28 similar to that at the opposite end of the beam connects the rod 27 and the beam. A weight 29 consisting of divisional portions 30 is placed upon the driven end 24 of
35 the rocking lever 17 and it serves to counterbalance an excess load acting upon the opposite end 22 thereof and which excess load is due substantially to the weight of plunger rod 12. Clamps
40 31 are shown for securing the weight upon the rocking lever at a desired distance from the fulcrum point 18.

The recording device which indicates the relative amount of overload in an unbalanced condition of the pump, is more or less diagrammatically shown in Fig. 1 as by a reciprocable spring
45 tensioned recording strip 32, a pulley arrangement comprising pulleys 33, 33a, 33b, pulling strings 34 and 34a to engage over the respective pulleys between the recording device and the pump rod, and a member or arm 35 clamped to
50 the plunger rod 12 to hold one end of the pulling string 34. This general arrangement shows that the reciprocation of the pump rod 12 will produce a corresponding up and down movement of the recording strip 32. The pulleys 33, 33a, 33b incidentally are shown to embody a ratio which
55 will transmit an increased average speed such as may be considered suitable to the recording strip 32.

The novel indicator and recording device is more clearly shown in the detail Figures 2, 3, 4,
65 5. A suitable steel frame 36 has mounted at the top portion a spring tensioned reel arrangement which comprises the recording strip 32 wound upon a tubular member 37. A rotatable shaft
70 38 is centrally guided inside the tubular member 37 which also houses a helical spring 39 which is to tension the recording strip 32. One end of the spring is fixed at 40 to the shaft 38, the other end of the spring being fixed at 41 to the tube member 37.

The right hand end portion of the interior shaft 38 carries a collar 42 by means of which it is centered and guided in the tube member 37. The right hand end portion of the tube member expands into a dished portion 43 which forms one half of a clutch arrangement inasmuch as it has a line of indentations which constitute a circular toothed rack 44. The right hand end of the shaft 38 is squareshaped as indicated at 45 and carries a head or terminal in the form of a complementary clutch-member 46 rotatable with the shaft 38.

This complementary half of the clutch carries a swingable lever or handle 47 which can be manipulated to selectively engage in any of the indentations of the toothed rack 44. The clutch portion 46 is furthermore formed with a cylindrical reduced portion 48 rotatable in a bearing member 49 mounted on the steel frame 36. The bearing 49 is of the single split springy type as indicated in the views of Figures 3 and 4 by the slit 49a, and it can be tightened to grip the portion 48 by means of a knurled screw bolt or tightening screw 49b.

The left hand end portion of the tubular member 37 has a reduced portion 50 in which is rotatably guided the left hand end portion of the interior shaft 38, the portion 50 in turn being guided for rotation in a bearing member 51 fixed upon the steel frame 36. The reduced portion 50 is further stepped down to form a protruding end in the shape of a threaded cylindrical extension 52. A knob 53 fits rotatably over the extension 52 and has a reduced portion 54 which serves for winding thereon a string 55 for the purpose of operating a trip or starting arrangement hereinafter to be described. A lock nut 53a upon the thread of extension 52 is countersunk into the knob 53 and serves to fix the relative position of the knob 53 upon the extension 52 in that it tightens the knob 53 against a shoulder 56 of the extension 52.

Upon the steel frame 36 is further mounted a plate 57 to serve as a backing for the recording strip 32, a bracket 58 to carry mounted thereon a time marking device which is shown to be in the nature of a metronome 59 indicated by the housing 60, a key 61 for winding the clockwork thereon, and an oscillating member or pendulum 62 actuated by the clockwork and adjustable to oscillate at a desired adjustable frequency. The pendulum 62 carries a writing or recording point 63 and it is also shown to be adjustably mounted upon its threaded oscillating shaft 64 by means of a pair of lock nuts 65 which permit to adjust the pendulum longitudinally as well as transversely of its shaft and relative to the writing surface of the recording strip. The metronome in turn can be bodily adjusted in a lateral way upon its supporting bracket 58 due to the provision of anchoring screws 66 extending through slots 67 in the base of the metronome housing. The supporting bracket is U-shaped in plan view to surround transversely the recording strip 32, the shanks of the bracket being fastened to the corresponding shanks of the steel frame 36.

Fig. 2 and Fig. 5 furthermore illustrate the embodiment of an automatic trip arrangement which is settable in such a way as to start the pendulum 62 of the metronome 59 swinging by releasing it at a certain moment in synchronism with the pump stroke. To this end the pendulum is shown to have pivoted thereon a retaining hook-member 68 which is determined in its pivotal movement upwardly by a stop 69 fixed upon

the end of pendulum 62. In upper limit position as determined by this stop (see Fig. 2 full lines) the hook 68 is conditioned to engage behind a downward protrusion 70 formed at the outer end of a helical spring 71 shown to be made of flat spring metal, the spring having its inner end fixed as at 72 to the steel frame 36.

That is to say, preparatory to starting the metronome 59, the pendulum 62 is held in the full line position of Fig. 2 by having the hook member 68 engage upon the protrusion 70 of the helical spring 71. As soon as the pulling of the recording strip 32 causes rotation of the tubular member 37 and thereby the tensioning of the string 55, the latter will lift the end portion of spring 71 and thereby disengage the protrusion 70 from the hook member 68. The hook member 68 is limited in its upward pivotal position by the stop 69, but when released as just described it will drop, thus setting the pendulum 62 free to oscillate as indicated by the dot and dash position thereof under the impulse of the clockwork of the metronome 59. The string 55 can be adjusted with just enough slack to effect the proper timing of the release relative to the movement of the recording strip 32.

The steel frame 36 also carries a guide roller 73 as in bearings 74, for the purpose of holding the recording strip 32 in proper relationship to the backing plate 57. A detachable clamp device 75 grips the free end of the recording strip and connects it with the pulling string 34a attached to the pulley 33b.

In order to have the device in proper operating order the spring tension for the recording strip, as well as the starting device must be properly adjusted.

To establish a desired torsional tension of the spring 39 the lever 47 is disengaged from the toothed rack 44. Also the lock nut 53a at the opposite end of the reel is loosened and the trip string 55 left with ample slack, leaving the tube member 37 substantially free to rotate. Now, in order to give the spring 39 the necessary tension the knurled screw 49b is tightened and the clutch member 46 together with the shaft 38 held stationary. By pulling the recording strip 32 down and off the reel a suitable length, the spring 39 is tensioned to a suitable degree, whereupon the clutch lever 47 is thrown into a corresponding indentation of the rack 44 and screw 49b again loosened to leave the clutch member 46 free to rotate with the reel or tube member 37. Under the spring tension thus established the recording strip 32 is allowed to rewind itself.

The pulling strings 34 and 34a are attached to and run over the respective pulleys 33, 33a, 33b, the strings being made of the proper total length to correspond to the length of the pump stroke, when the string 34 is connected to the arm 35 at the pump rod 12. The metronome 59 is positioned and fixed upon the bracket 58 in proper relation to the center line of the recording strip, as by slot connections 66, 67. Proper writing relationship is established between the recording strip 32 and the writing point 63 as the pendulum is adjusted upon the oscillating shaft 64 by means of the lock nuts 65.

Next comes the adjustment of the automatic starting or trip device. Assuming the detent hook member 68 as being held by the detent spring 71, the trip string 55 is given a certain amount of slack and the lock nut 53a tightened so that the knob 53 will be fixed to the extension 52 of the tube member 37 by engagement against the shoulder 56.

der 56. There should be just so much slack of the string 55 that it will be taken up by the rotation of the recording reel when the same reaches a certain predetermined position which corresponds to a dead center position of the pump-rod, at which time the trip string 55 will disengage the free end of the spring 71 from the hook member 68 allowing the latter to drop into its idle position as indicated in the dot and dash position of the pendulum. More specifically it is desired that the amount of slack of the string 55 be so adjusted that the vertical or zero position of the released pendulum 62 will substantially coincide with the dead center position of the pump-rod. If synchronized in this manner the recording device will furnish relatively symmetrical diagrams of a desired character. It is understood that a suitable frequency of pendulum oscillations is best chosen with respect to the frequency of pump strokes.

With the adjustments made as described above a load diagram of suitable characteristics can be recorded: during each pump stroke the pendulum performs a fixed number of oscillations which register as undulating lines upon the recording strip whose up and down movement is coordinated to the movement of the pump through the respective string and pulley connections.

Considering a pumping cycle of two consecutive strokes, that is to say an up-stroke and a down-stroke, the mechanism will record two intersecting undulating lines upon the recording strip. The points of intersection furnish a criterion inasmuch as this relative location indicates the relative load difference in a sequence of the two strokes.

Figures 6 and 7 indicate a theoretical case of unbalanced and balanced pump operation respectively. Figs. 8 and 9 are graphs taken in actual operation. There will now first be given an interpretation on the basis of the theoretical diagrams of Figs. 6 and 7.

More specifically considering the unbalanced condition of Figure 6 during the upstroke of the plunger rod 12 the record strip 32 will be pulled downwardly while the writing point 63 describes thereon an undulating line 76. The return or down-stroke of the plunger rod 12 reverses the movement of the record strip while the writing point 63 continues its rhythmic oscillations. In other words, during the return stroke a second undulating line 77 appears so that the undulations of the two lines intersect each other. The fact that the respective amplitudes or phases are staggered or shifted against each other immediately furnishes a basis for direct comparison of the respective load conditions. Obviously such staggering of the phases is caused by the reversal of the stroke direction while the pendulum or writing point 63 continues its uniform rhythm. The points *a, b, c, d*, etc. in Fig. 6 constitute points of intersection, and their distance from the center line O—O can be said to be approximately indicative of the amount of load discrepancy between up-stroke and down-stroke.

In other words, the closer these points of intersection are located towards the center line O—O of the diagram the more nearly balanced is the machine. That is to say, the perpendicular distance of the points of intersection from the center line O—O is an indication of the amount of weight correction needed. Still in other words, the less symmetrical and regular the intersecting lines appear, the more counterweight correction is needed; on the other hand, the more evenly

up- and down-stroke are balanced against each other, the closer will the points of intersection approach the center line O—O, and the more symmetrical and regular will be the diagram. That portion of the diagram which is located intermediate the ends thereof is the more important or more convenient for the interpretation. The indications in that part of the diagram are evidently more distinct than the end portions due to the relatively higher speed of the pump rod in this phase, which in turn records longer undulations and more clearly defined points of intersection. A suitable relative speed of the recording strip may be established by a suitable ratio of the movement transmitting pulleys 33, 33a, 33b.

Consequently in order to correct this unbalanced condition as charted in the diagram Figure 6, the weight balance of the machine must be adjusted by furnishing the proper amount of counter weight to the rocking lever 17 of the pump, so that the load imposed upon the prime mover 25 will be substantially the same for each pump stroke. If this is done a balanced condition will be reflected in a new diagram (see Fig. 7) where it is noted that now the points of intersection X, Y, Z, etc. coincide more nearly with the center line. The phases of the two undulating lines appear to be shifted against each other substantially 180° as it should be.

Where the balancing of the load as between up stroke and down stroke of the pump is the main objective, the charts or graphs obtained according to this invention will lend themselves to a mode of interpretation which is somewhat at variance with that which considers merely the location of the points of intersection relative to the zero line. It should be understood that in a practical case the pump, in fact, may have been adjusted to operate under its practical optimum of balanced condition, whereas some or all of the points of intersection are still perceptibly off the zero line.

That is to say, while it is a theoretically ideal condition to have these points coincide with the center line, it is in a practical instance not necessarily attained, although, on the other hand, a practical optimum adjustment as to operation may have been reached.

Such or a similar irregularity may be due, as a matter of course, to some mechanical insufficiency or irregularity in the operation of the pump proper. For this reason and in order to suggest to some extent an average practical operating condition, the intersection points in the theoretical Figure 7 are shown to be slightly off the zero line.

Consequently, to use the points of intersection as a criterion for load balance, may be considered as a means of quick approximation in the determination of the condition sought, whereas a somewhat different and in a way more accurate mode of interpretation will now be described.

Thereafter it should be understood that a somewhat more accurate mode of determination of the load balance between up stroke and down stroke depends upon the number of oscillations which correspond to a fixed length of plunger-rod travel for both the up stroke and the down stroke. That is to say, it depends upon the determination of how many oscillations of a fixed frequency go into a fixed length of plunger-rod travel for the up stroke, on the one hand, and for the down stroke, on the other hand. The difference in the respective numbers of oscillations is to be indicative and a criterion of the

degree of load balance. If subsequently the proper amount of counterbalance be provided, the total of oscillations during the up stroke will be substantially equal to the total of oscillations during the down stroke.

This means that the total time for the up stroke is equal to that for the down stroke, and this is in keeping with the fact mentioned above that concurrent with such condition of time equality, a desirable operating condition or load balance is attained. Such a condition can be attained according to this invention in a relatively simple fashion, inasmuch as the difference between the respective numbers of oscillations can be most accurately determined from the chart, that is, from the relation of the undulating lines to the zero line O—O therein. The undulating line created by the oscillations of the pendulum 62, by virtue of its intersections with the zero line O—O, denotes absolutely the time it takes the plunger rod to move the distance between two points corresponding to any of the intersection points. Proportionately, and by way of interpolation, it is also possible to determine fractions of the travel time represented by the distance between two intersection points.

The importance of the chart in Fig. 7, in view of the interpretation just described, will now be more clearly understood, inasmuch as it shows a substantially equal number of oscillations for both the up stroke and the down stroke, irrespective of the fact that some of the intersection points do not coincide with the zero line O—O. In Fig. 6, as a matter of contrast, while the intersection points are shown to be off the zero line O—O with a degree of exaggeration, the dotted line has a considerably lesser number of oscillations than the associated full-line curve in this diagram. This difference of oscillations, although hypothetical in this tentative example, is an indication that the plunger rod, in drawing the dotted line of the down stroke, would travel faster than it would were it to draw the full line curve of the up stroke.

As a matter of definition, one full oscillation of the pendulum corresponds to a double bend in the undulating curve and it shall be called the amplitude of the pendulum movement, and it corresponds to the movement of the pendulum from the time it leaves a fixed point to the time it returns to that point. One amplitude therefore consists of four quarter amplitudes and in the following the lengths of the curves in question shall be defined as the sum total of a number of quarter amplitudes.

Consequently it will be noted in Fig. 6 that the curve for the up stroke (full line), counting from the point P, where it happens to intersect with the zero line O—O, as well as with the down stroke (dotted line), includes sixteen quarter amplitudes, whereas the down-stroke line comprises only twelve quarter amplitudes, indicating that there exists an insufficiency of counterweight, which causes the plunger rod to move faster on the down stroke than on the up stroke.

Assuming now, that, as a consequence of the findings from the chart in Fig. 6, an adequate amount of counterbalance weight had been added and the balance restored to a fairly ideal degree, such balanced condition would express itself in a diagram similar in character to the one shown in Fig. 7. Here the points of intersection of the undulating lines are shown to have shifted onto or relatively close to the zero line O—O. Counting the respective numbers of quarter amplitudes

for each of the undulating curves of Fig. 7, and starting the count from the point Q where approximately both lines shall be said to have an intersection with the zero line O—O, it will be noted that now both the up stroke and the down stroke are shown to include sixteen quarters of an amplitude, indicating that a desired degree of balance has been reached.

It should be clear that the hypothetical charts of Figs. 6 and 7 have been shown in order to illustrate more drastically the graphical distinctions between a maladjusted and a well-adjusted load condition. That is to say, in Fig. 6 there is shown an exaggerated condition of maladjustment, whereas Fig. 7 represents an adjusted condition reflected in a diagram of such a relatively high degree of regularity as is in reality not readily attained considering general deficiencies of actual apparatus efficiency.

Consequently, then, in passing on to the discussion of the diagrams or charts in Figs. 8 and 9, taken in actual operation, it will be noted by comparison that the distinguishing characteristics between them do not appear to be as obvious and contrasting as those of Figs. 6 and 7, on the face of it, and with respect to regularity of the intersection points. Nevertheless, if interpreted on the basis of the respective numbers of oscillations of the respective curves, and on the basis of time differences or time equalization, distinct criteria will be found to exist in the diagram representing the unbalanced condition (see Fig. 8), as well as in the diagram representing the adjusted condition (see Fig. 9).

Relative to Fig. 8, criteria for the degree of unbalance are recognized not only in the off-center location of all of the intersection points, but notably also in the existing difference in the number of oscillations, the full-line curve (up stroke) being appreciably longer than the dotted line taken over a characteristic portion of the length of plunger-rod travel. As a result of the addition of a suitable amount of counterweight to restore balance between up stroke and down stroke, there is then obtained a diagram or chart of the type according to Fig. 9. Applying now the test of equality of oscillations for the two strokes of the operating cycle, these oscillations will be found to be more nearly or substantially equal for both up stroke and down stroke over the length or portion of length of plunger-rod travel. The points of intersection have moved somewhat closer to the zero line O—O although with an amount of irregularity. Conclusively, however, since the respective numbers of oscillations for the respective strokes have been substantially equalized, this may be considered as the adjusted condition irrespective of a still existing irregularity in the location of the various intersection points.

An actual count of the respective numbers of oscillations in Fig. 8 may be based upon the intersection point R of the up stroke (full line) with the zero line O—O, which intersection point, of course, corresponds to a certain plunger-rod position. Counting from that point in the direction of the upward arrows marking the direction of the up stroke undulating line, that curve will be found to include fourteen quarter amplitudes, whereas the down stroke (dotted line) counting in the direction of the downward arrows, includes only twelve and a fraction of a quarter or somewhat less than thirteen quarter amplitudes. Assuming the time for one quarter amplitude to be 0.15 second, the time for the up stroke

portion from R to the top or upper end of the stroke is $14 \times 0.15 = 2.1$ seconds. The time for the down stroke over the identical length of plunger-rod travel is $12 \times 0.15 = 1.8$ plus the time elapsing while the recording point of the pendulum moves from R¹ to R², which fractional time, as found by way of interpolation, is 0.1248 second, making the total time for the corresponding down stroke portion 1.9248 second. In terms of percentage, the down stroke then is

$$\frac{2.1}{1.9248}$$

or 91.6% of the up stroke. Incidentally, it should be clear that the point R² upon the down-stroke curve is found by striking the arc of the recording point of the pendulum through the point R.

On the basis of this determination, a desirable amount of counterweight is added, and consequently the diagram of Fig. 9 is obtained. Performing again the count of oscillations, the point S is chosen as a starting point for the up stroke and twelve quarter amplitudes are counted to the top of the curve or upper dead-center position of the plunger rod. The count for the down stroke (dotted line) furnishes twelve and a fraction quarter amplitudes, that is to say, approximately the same as for the up stroke, indicating that a condition of improved balance has been reached. The fraction is equivalent to the time during which the recording point of the pendulum moves from the point S¹ to the point S², and it is determined by interpolation. This again is obvious when the arc of pendulum movement is struck through the point S. Again the time basis is 0.15 second for one quarter amplitude so that the total time for this particular up-stroke portion is $12 \times 0.15 = 1.8$. The total time for the identical down-stroke portion is 12×0.15 plus the time used while recording point of the pendulum swings from S to S², or approximately $1.8 + 0.0245 = 1.8245$ second, making the time for the down-stroke portion equal 98.65% of the time for the up-stroke portion.

In the operation of taking the charts or diagrams it is desirable to synchronize the swing or frequency of the pendulum relative to the upper dead-center portion of the plunger rod in such a manner that at the end of an up stroke the central or zero position of the recording point of the pendulum will coincide with the zero line O—O. Such synchronism will furnish the basis for a ready interpretation of the curves.

One practical way of attaining synchronism is by a corresponding adjustment of the automatic starting or trip device, as herein described. Another way is to have the recording point at rest in the central or zero position, while taking an up stroke, which will record the length of travel of the up stroke, then to have the device register a trial chart and if the recording point fails to coincide with the upper terminal point or dead-center position of the plunger-rod stroke, to adjust the frequency of vibrations of the pendulum until it does.

Whereas the method of relative load determination just described may be practiced by considering certain differentials in the appearance of two associated curves, this method basically also permits of numerically determining the actual speeds of the plunger rod or, in principle, of any other reciprocating movement.

Diagrams taken in this manner therefore offer the possibility of numerically determining the actual speeds of the plunger rod at various phases

of its stroke. Assuming for instance that say 1 foot of plunger stroke corresponds to a certain fraction of the length of the diagram, and assuming the frequency of the pendulum 62 to be known, it is possible to determine momentary speeds of the plunger rod from the corresponding dimensions of the graph.

What I claim is:

1. An apparatus arrangement for determining the state of load balance in the plunger stroke cycle of a reciprocating oil well plunger pump, which comprises a reciprocably movable chart, movement transmitting connecting means between the pump plunger and the chart for controlling the reciprocating movement thereof in unison with the plunger movement, means for tensioning the chart with respect to the movement imparting force of the plunger, a member reciprocating in equal time intervals, and means for making a continuous record of the movements of said member upon said chart and transversely to the direction of movement of said chart.

2. An apparatus arrangement according to claim 1, with the addition of means for starting the operation of said reciprocating member relative to a predetermined point of chart movement.

3. The method of determining the state of load balance with respect to the two strokes in the operating cycle of a reciprocating pumping apparatus, which comprises measuring the period of time required for a portion of the one stroke, measuring the time required for a corresponding portion of the opposite stroke, and comparing the times so measured.

4. The method of determining the state of load balance with respect to the two strokes in the operating cycle of a reciprocating pumping apparatus, which comprises measuring the period of time required for a portion of the one stroke, which portion ends in a dead center of the stroke cycle, measuring the time required for an immediately subsequent corresponding portion of the opposite stroke, which portion in turn begins at said dead center of the stroke cycle, and comparing the times so measured.

5. The method of determining the state of load balance with respect to the two strokes in the operating cycle of a reciprocating plunger pumping apparatus, which comprises measuring the distance traveled by the plunger in one direction during a period of time, measuring the distance traveled by the plunger in the opposite direction during a substantially like period of time, the measurements of said distances being based upon a like position of the plunger with respect to both strokes of the cycle, and comparing the said distances traveled.

6. The method of determining the state of load balance with respect to the two strokes in the operating cycle of a reciprocating plunger pumping apparatus, which comprises measuring the distance traveled by the plunger in one direction during a period of time, measuring the distance traveled by the plunger in the opposite direction during a substantially like period of time, the measurements of said distances having as a basis of comparison and as a common reference point a dead center position of the pump plunger and comparing the distances thus traveled.

7. The method of balancing the load in the upstroke and the downstroke of an operating cycle of a reciprocating oil well plunger pump, which comprises determining the average rela-

tive load in each of the two strokes of the pumping cycle by way of taking corresponding stroke-time measurements for both strokes, determining the average load difference between said strokes by way of comparing the results of said stroke time measurements as a criterion of load unbalance, and applying an amount of counterweight correction to the pumping apparatus substantially sufficient to offset said unbalance.

10 8. The method of balancing the load in the upstroke and the downstroke of an operating cycle of a reciprocating oil well plunger pump which comprises measuring a series of increments of distance traveled by the plunger as defined by a
15 corresponding series of consecutive small time intervals while the plunger moves in one direction, measuring the same number of substantially corresponding increments when the plunger moves in the opposite direction, and applying an
20 amount of counterweight correction to the pumping apparatus substantially sufficient to offset unbalance in making corresponding increments of the upstroke and the downstroke substantially equal.

9. Apparatus arrangement for determining the state of load balance in the stroke cycle of a reciprocating pumping apparatus, which comprises a recording device having a chart member reciprocably movable substantially in unison with the stroke cycle, a recording member reciprocably movable transversely of the chart movement, and motivating and control means constructed and adapted to effect movement of said recording member in a manner relative to the movement of said chart member to produce a pump velocity indicative record thereon, the coordination of the respective movements of both said members being such that upon said chart moving in the one direction there is made a continuous velocity indicative record corresponding to one stroke of the cycle, and a similar record corresponding to the other stroke as the chart moves in the opposite direction, both said records being confined between limits defined by the dead center positions of said reciprocable chart.

GEORGE M. HIGGINSON.