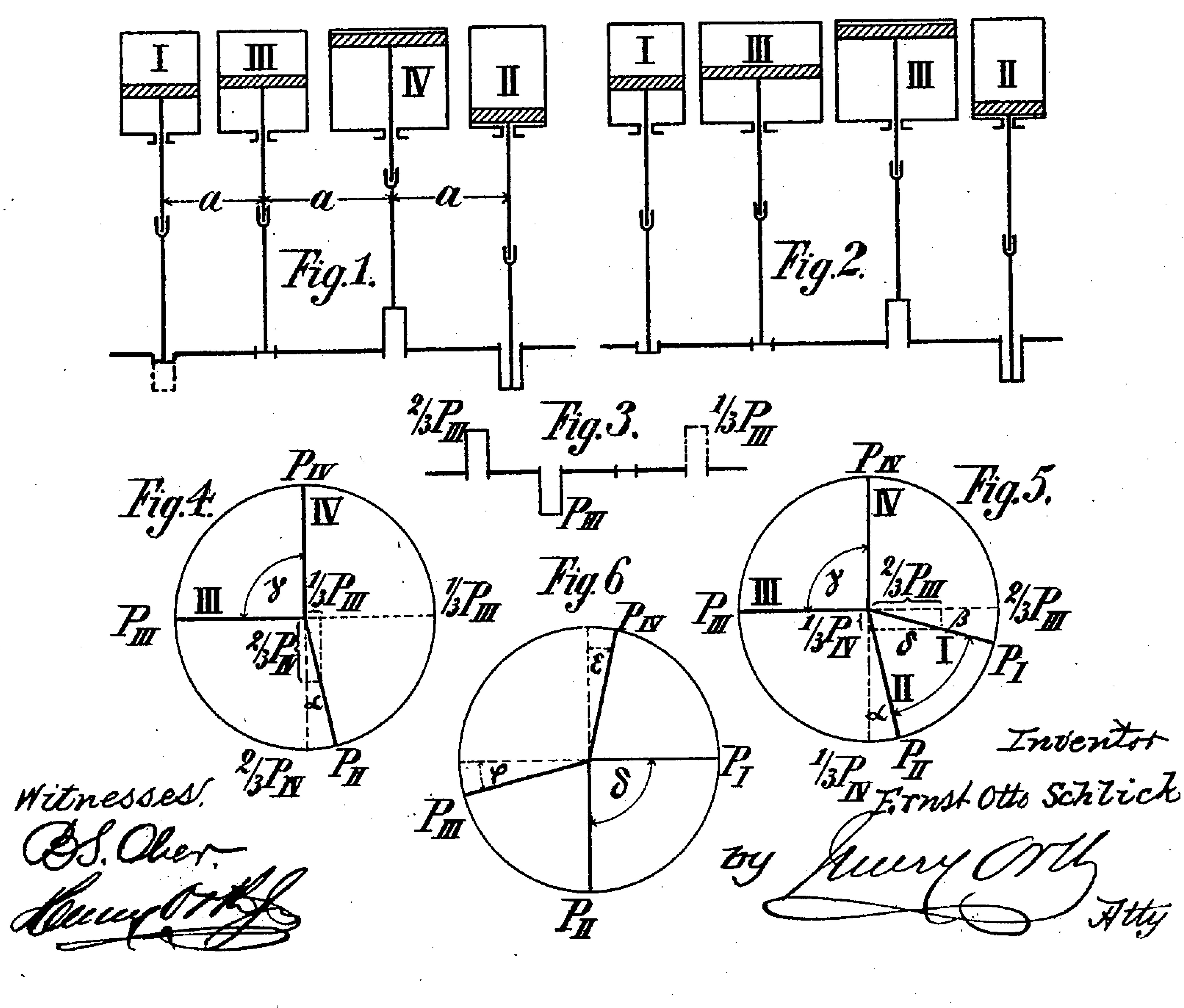
(No Model.) 4 Sheets—Sheet 1.

E. O. SCHLICK.

STEAM OR LIKE MOTIVE POWER ENGINE.

No. 594,288. Patented Nov. 23, 1897.



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(No Model.) 4 Sheets—Sheet 2.

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STEAM OR LIKE MOTIVE POWER ENGINE.

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Fig. 7.

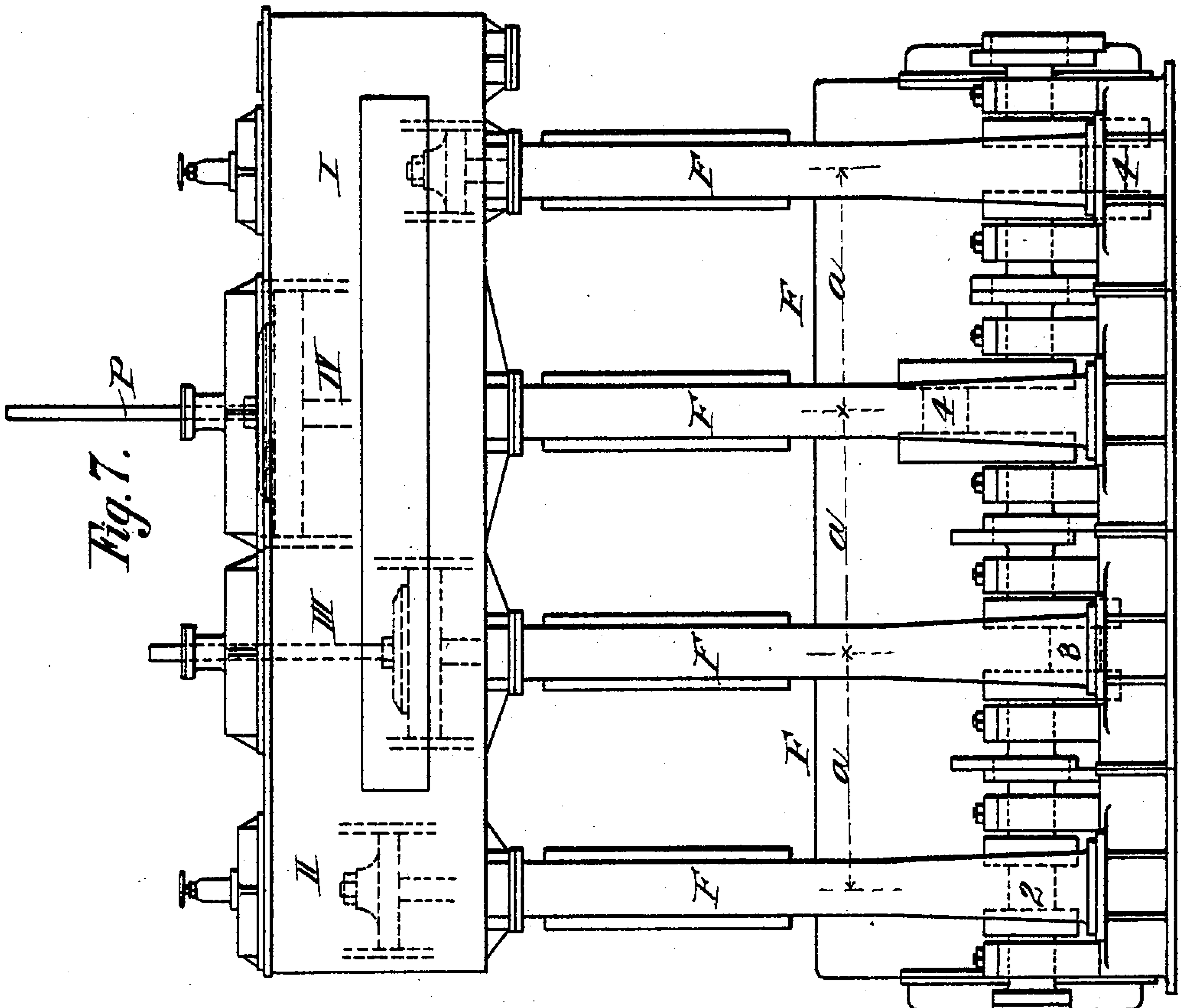
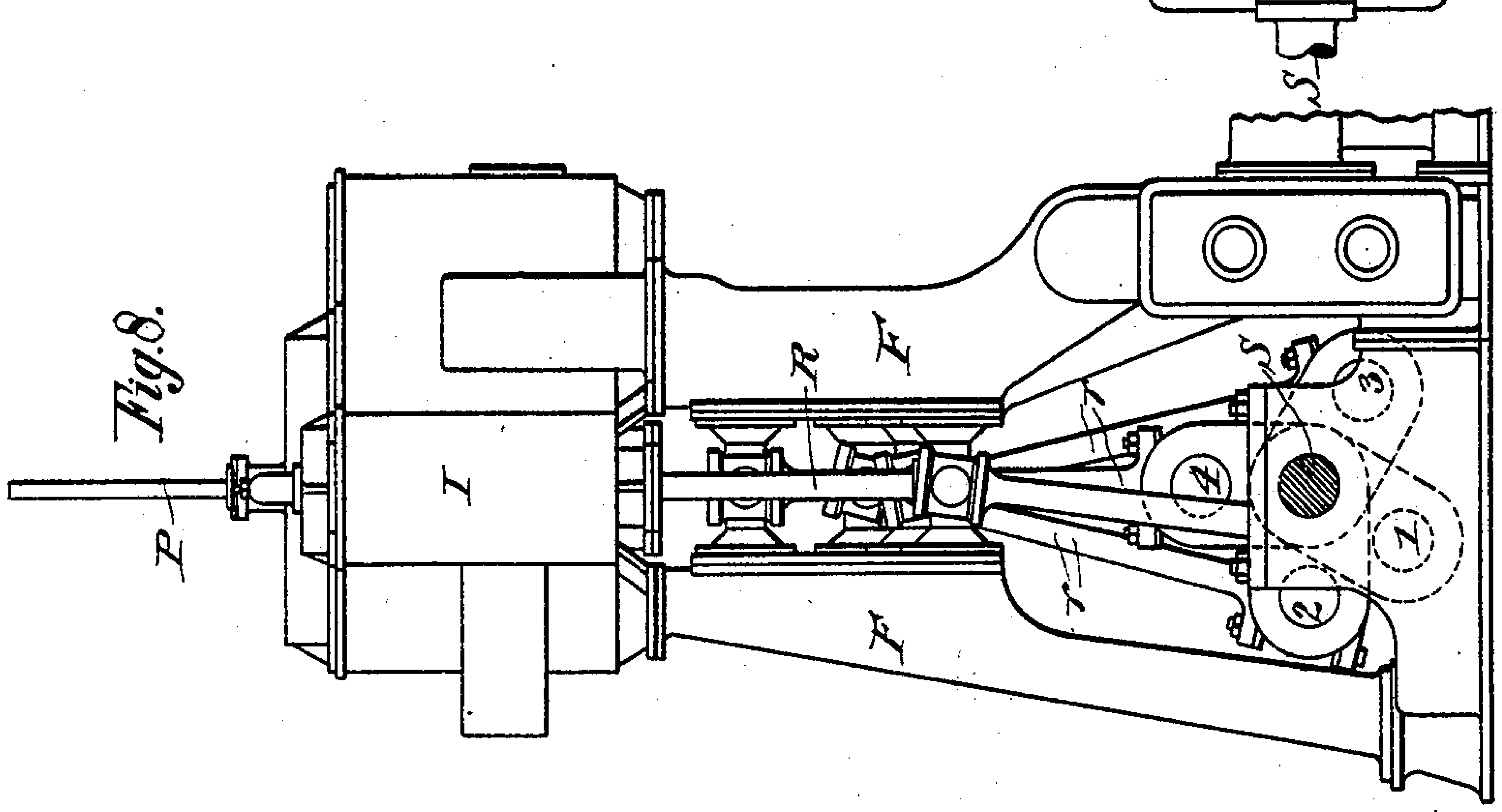


Fig. 8.



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(No Model.) 4 Sheets—Sheet 3.

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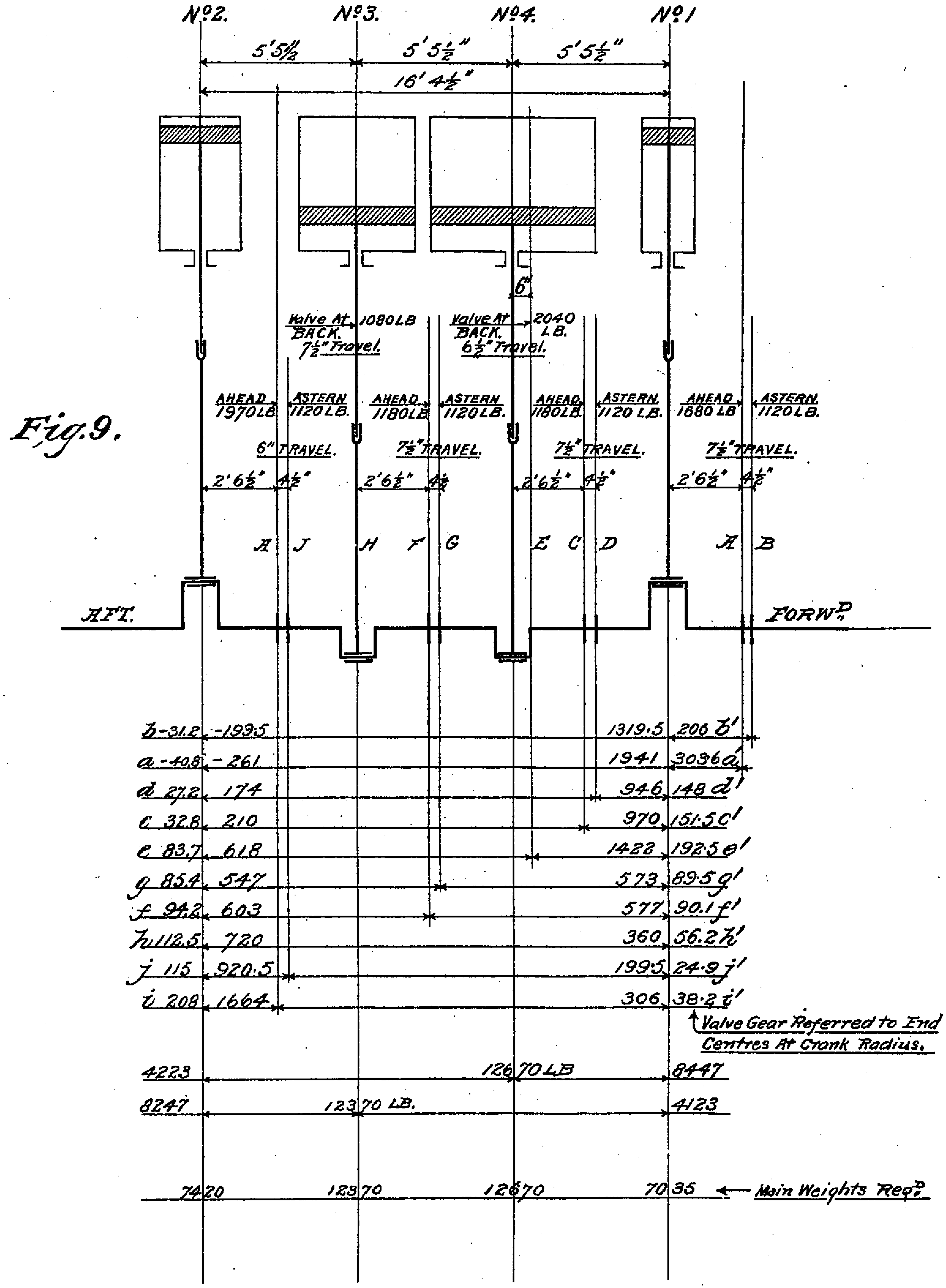

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(No Model.)

4 Sheets—Sheet 4.

E. O. SCHLICK.

STEAM OR LIKE MOTIVE POWER ENGINE.

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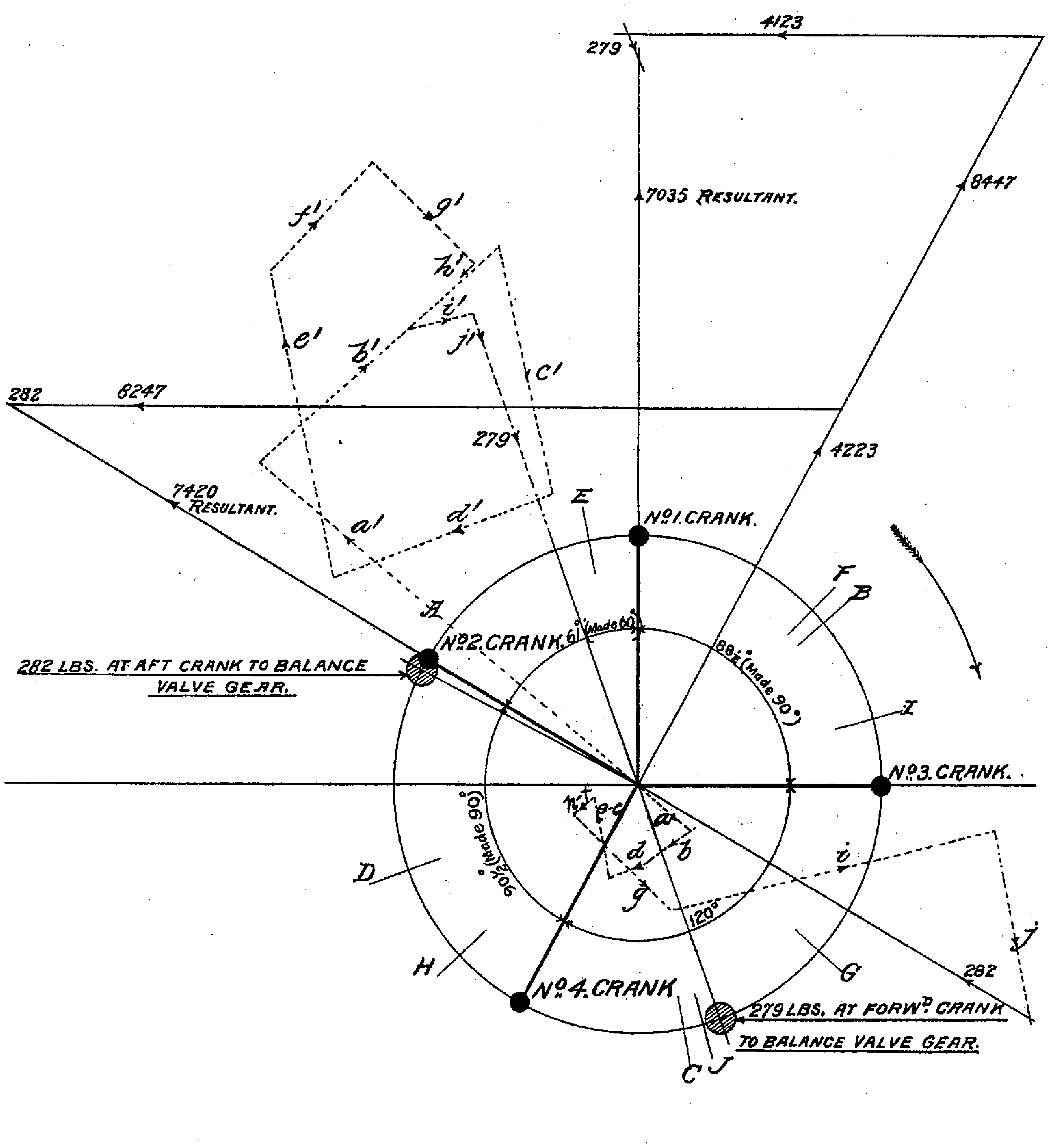
Fig. 10.



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UNITED STATES PATENT OFFICE.

ERNST OTTO SCHLICK, OF HAMBURG, GERMANY, ASSIGNOR TO THE YARROW SCHLICK & TWEEDY SYSTEM, LIMITED, OF LONDON, ENGLAND.

STEAM OR LIKE MOTIVE-POWER ENGINE.

SPECIFICATION forming part of Letters Patent No. 594,288, dated November 23, 1897.

Application filed September 6, 1895. Serial No. 561,629. (No model.) Patented in Germany November 10, 1893, No. 80,974; in England February 8, 1894, No. 2,813; in France February 9, 1894, No. 236,163; in Belgium March 12, 1894, No. 108,979; in Italy March 15, 1894, No. 35,953; in Hungary December 12, 1894, No. 1,782, and in Austria June 30, 1895, No. 45/2,364.

To all whom it may concern:

Be it known that I, ERNST OTTO SCHLICK, a subject of the German Emperor, and a resident of Hamburg, in the German Empire, have invented certain new and useful Improvements in Steam or Like Motive-Power Engines, (for which I have obtained a patent in Germany, No. 80,974, dated November 10, 1893, and assigned to Stettiner Maschinenbau Actien-Gesellschaft Vulcan at Bredow, near Stettin, Germany; in Great Britain, No. 2,813, dated February 8, 1894; in France, No. 236,163, dated February 9, 1894, and additional patent No. 236,163, dated December 20, 1894; in Belgium, No. 108,979, dated March 12, 1894, and additional patent No. 113,319, dated December 22, 1894; in Italy, No. 35,953, dated March 15, 1894, and additional patent No. 37,909, dated December 24, 1894; in Hungary, No. 1,782, dated December 12, 1894, and in Austria, No. 45/2,364, dated June 30, 1895;) and I do hereby declare that the following is a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same, reference being had to the accompanying drawings and to letters or figures of reference marked thereon, which form a part of this specification.

My invention has relation to multiple-cylinder steam or like motive-power engines with more than three cylinders, the pistons of which act singly or in groups upon the several respective cranks of the crank-shaft. In power-engines of this class the moving elements or masses engender considerable forces that act injuriously upon the engine itself as well as upon its support or foundation. For instance, in vertical engines having their cylinder-axes in one and the same plane there are forces (thrust and pull) at hand that tend to move or displace the engine up and down alternately in the direction of the piston-rods and such that have the tendency to alternately tilt the whole engine in one or the other direction from the ends of the crank-shaft. These forces act the more injuriously where it is impossible to provide a foundation capable of resisting the same, as in the case of marine engines, or in case a fixed foundation or support cannot be provided, as in the case of locomotives, and the only remedy heretofore known is the use of dead-weights. The latter have, however, not only the disadvantage of greatly increasing the bulk and weight of the engine, being more or less obstructive and rendering attendance more difficult as well as dangerous; but although the reaction forces acting in the direction of the piston-rods are practically compensated or counterbalanced other similarly injurious reaction forces that act at right angles to the plane of the piston-rods are engendered, so that, practically speaking, the said reaction forces produced by the weights of the moving masses or elements of the engine are not annulled or counterbalanced, but undergo a change of direction of about ninety degrees; nor is it possible to compensate or annul the effect of these reaction forces by a mere relative angular adjustment of the several cranks on the crank-shaft.

The object of my invention is not only to practically compensate or counterbalance the injurious results due to the action of the said reactive forces referred to in engines of the kind under consideration, but also to utilize the moving parts or elements of the engines themselves as a means for accomplishing the desired result, avoiding thereby the use of the undesirable dead-weights.

To these ends the invention consists, essentially, in the proper relative angular arrangement of the cranks on the crank-shaft, in the proper relative length of the crank-arms, in the proper relative distance between the cranks or the cylinder-axes, respectively, and in the proper relative distribution of the weights of the moving elements or masses, all in such proper relation that the latter will act upon the crank-shaft and the foundation, respectively, in such a manner that the two kinds of reaction forces above referred to—that is to say, the reaction forces tending to move or displace the crank-shaft alternately in the direction of the piston-rods and the couple of forces acting in a plane passing through the cylinder-axes and having the tendency to tilt the engine and its support—are practically avoided or compensated, the arrangement being then that there cannot arise in the engine either any free thrust or pull forces in the direction of the piston-rods nor any free couple of tilting forces in the plane of the cylinder-axes. These balancing effects may be obtained, if required, not only in the plane of the piston-rods, but also in any other plane passing centrally through the crank-shaft. The slight and immaterial imperfections due to the finite length of the connecting-rods, eccentric-rods, and the like need not be particularly considered in this case.

That my invention may be fully understood I will describe the same in detail, reference being had to the accompanying drawings, in which—

Figures 1 and 2 are diagrammatic views of steam-engines illustrative of the mode of carrying out my invention, and Figs. 3 to 6 are like views illustrative of the relative position of the cranks. Figs. 7 and 8 are side and end elevations, respectively, of an engine constructed according to this invention; and Figs. 9 and 10 show a balance diagram of a four-crank engine such as shown in Figs. 7 and 8.

In the quadruple and triple expansion engines with four cranks each (shown by Figs. 1 and 2, respectively) it may be assumed, for the sake of simplicity, that the moving elements (piston, piston-rod, connecting-rod, &c.) of each cylinder operate upon a separate crank. In some cases, however, the moving elements or masses of two or more cylinders may be caused to act upon a single crank. In view of the fact that the moving elements of the two intermediate cylinders must be heavier than those of the outer cylinders (and this is a characteristic feature of this construction) it is preferable to arrange the larger cylinders between the smaller ones, though this is not absolutely necessary so long as the heavier masses are caused to act upon the intermediate cranks.

In the quadruple-expansion engine, Fig. 1, the steam flows successively to the cylinders I II III IV and from the latter to the condenser. In order to shorten the steam-passages, it is in many cases advisable to reverse the relative position of the cylinders III and IV. The triple-expansion engine, Fig. 2, is supposed to have two low-pressure cylinders III, and in order to shorten the steam-passages it will also be advisable to arrange cylinder II alongside of cylinder I. The kind of power-engine, provided it has not less nor more than four cranks, is absolutely immaterial in so far as the nature of my invention is concerned so long as provision is made for counteracting the reaction forces through the medium of the moving elements themselves. The distances between them in the direction of the crank-shaft, the length of the crank-arms, and particularly the relative angles formed by the cranks must be definitely related.

Although for practical reasons it may sometimes not be desirable to exactly or entirely counterbalance the reaction forces irrespective of the immaterial errors due to the finite length of the connecting-rods, yet the construction should be such as to render possible the said counterbalancing of the moving masses without the use of dead-weights at all.

In order that my invention may be fully understood, I will describe the same in respect of a quadruple-expansion engine, referring to Fig. 1 of the drawings, it being assumed that the weights of the moving elements of the cylinders III and IV are represented by P III and P IV, respectively, Fig. 4, and that the angle between the two cranks is known, and for the sake of simplicity it may be assumed to be an angle of ninety degrees, and for the sake of further simplicity it will further be assumed that the distance a, Fig. 1, between the axes of proximate cylinders is equal and that all the crank-arms are of the same length. It will now only be necessary to find the weights of the moving elements of cylinders I and II and the relative angle of the cranks to which the pistons of said cylinders are connected, which is done as follows:

In order to compensate the reaction forces exerted by the weights of the moving elements of cylinder IV by means of the weights of the moving elements of cylinders I and II, it will be necessary to provide for the last two cylinders cranks of equal length that lie diametrically opposite the crank of cylinder IV. The force exerted upon the crank-shaft by the moving elements of cylinder II will, however, be greater than the force exerted upon said shaft by the moving elements of cylinder I in proportion as the distance between the centers of cylinders IV and II is smaller than that between the centers of cylinders IV and I. The sum of the weights acting upon the cranks of cylinders I and II should, therefore, be equal to the weight acting upon the crank of cylinder IV. Accordingly a force engendered by a weight equal to $\frac{1}{3}$ P IV and $\frac{2}{3}$ P IV, respectively, should be exerted by the moving elements of the cylinders I and II upon cranks arranged diametrically opposite the crank of cylinder IV in order to counteract the force exerted by the like elements of cylinder IV. In a precisely similar manner the force exerted upon the crank-shaft by the moving elements of cylinders I and II that will counterbalance the force exerted by the moving elements of cylinder III may be determined, namely: Weights equal to $\frac{2}{3}$ P III and $\frac{1}{3}$ P III, respectively, will have to act upon the cranks of cylinders I and II in order to compensate the force exerted upon the crank-shaft by the weight of the moving elements of cylinder III, Fig. 3, in which case the cranks of cylinders I and II would have to be arranged diametrically opposite the crank of cylinder III, Fig. 3.

If the relations that occur in the circle of the crank for the cylinder II, Fig. 4, are considered, it will be found that there should be exactly opposite the crank of cylinder III another, upon which a force of $\frac{1}{3}$ P III is exerted; but at the same time there should be opposite the crank of cylinder IV a crank upon which a force equal to $\frac{2}{3}$ P IV is exerted.

In view of the fact that it is not possible to arrange two cranks at the same time in one plane a single crank must be substituted therefor, the position of which, as well as the force acting thereon, will be determined by the resultant of the weights that would have acted upon the said two cranks. Hence if the value $\frac{1}{3}$ P III is carried, according to a certain scale, to a prolongation of the crank-arm of cylinder III, Fig. 4, and similarly the value $\frac{2}{3}$ P IV to a prolongation of the crank-arm of cylinder IV, the position of the crank-arm of cylinder II and the weight that should act thereon can be directly deduced from the parallelogram of forces. The position of and the weight that should act upon the crank for the cylinder I are obtained in the same manner, as clearly shown by Fig. 5. Thus if it be assumed that the angle γ, Figs. 4 and 5, formed by the cranks of cylinders III and IV is one of ninety degrees we will have the following formulæ:

$$(2)\quad P_1=\sqrt{(\tfrac{2}{3}\text{ P III})^2+(\tfrac{1}{3}\text{ P IV})^2}.$$

$$(3)\quad P_2=\sqrt{(\tfrac{2}{3}\text{ P IV})^2+(\tfrac{1}{3}\text{ P III})^2}.$$

$$(4)\quad \text{Tang. } \alpha=\frac{\frac{1}{3}\text{ P III}}{\frac{2}{3}\text{ P IV}}=\frac{\text{P III}}{2\text{ P IV}}.$$

$$(5)\quad \text{Tang. } \beta=\frac{\text{P IV}}{2\text{ P III}},$$

α and β being the angles formed between the cranks II and I and IV and III, respectively. If, on the contrary, the angle γ, formed by the cranks of cylinders III and IV, is not a right angle, then we have the following formulæ:

$$(6)\quad \text{P I}=\sqrt{(\tfrac{2}{3}\text{ P III})^2+(\tfrac{1}{3}\text{ P IV})^2+\tfrac{4}{9}\text{ P III PI cos. }\gamma}.$$

$$(7)\quad \text{P I}=\sqrt{(\tfrac{2}{3}\text{ P IV})^2+(\tfrac{1}{3}\text{ P III})^2+\tfrac{4}{9}\text{ P III P IV cos. }\gamma}.$$

$$(8)\quad \text{Sin. } \alpha=\text{sin. }\gamma\,\frac{\frac{1}{3}\text{ P III}}{\text{P II}}.$$

$$(9)\quad \text{Sin. } \beta=\text{sin. }\gamma\,\frac{\frac{1}{3}\text{ P IV}}{\text{P I}}.$$

If the weights acting upon the outer cranks and the angle formed by said crank are also known, the angular relation, as well as the weights that should act upon the intermediate cranks, can be obtained, and if the angle δ, Fig. 6, is a right angle we have the following formulæ:

$$(10)\quad \text{P IV}=\sqrt{(2\text{ P II})^2+(\text{P I})^2}.$$

$$(11)\quad \text{P III}=\sqrt{(2\text{ P I})^2+(\text{P II})^2}.$$

$$(12)\quad \text{Tang. } \varepsilon=\frac{\text{P I}}{2\text{ P II}}\text{ tang. }\frac{\text{P II}}{2\text{ P I}}.$$

If the angle δ is not a right angle, the formulæ will be:

$$(13)\quad \text{P IV}=\sqrt{(2\text{ P II})^2+(\text{P I})^2+4\text{ P II P I cos. }\delta}.$$

$$(14)\quad \text{P III}=\sqrt{(2\text{ P I})^2+(\text{P II})^2+4\text{ P I P II cos. }\delta}.$$

$$(15)\quad \text{Sin. } \varepsilon=\text{sin. }\delta\,\frac{\text{P I}}{\text{P II}};\ \text{sin. }\varphi=\text{sin. }\delta\,\frac{\text{P II}}{\text{P III}}.$$

The weights acting upon the outer cranks and the angle formed by said cranks may also be considered as known, (see Fig. 6,) and from this I can obtain in a quite similar manner the angular position of, as well as the weights, that should act upon the two intermediate cranks, Fig. 6.

The above formulæ apply only, as already stated, in cases where the lengths of the crank-arms and the distances between the cylinder centers are equal to each other. If, however, the lengths of the crank-arms differ, as well as the distances between the cylinder centers, the relations will naturally be of a much more complicated form. In determining the weights that act upon the various cranks the revolving elements—as the crank-pins, crank-arms, eccentrics, &c.—must also be considered, besides the reciprocating elements.

In a quadruple-cylinder engine in which the cylinder centers are equidistant and the crank-rods of correspondingly the same length, if the weights acting upon the separate cranks and the relative angles formed by the several cranks are determined by the foregoing statements, it will be found that the various forces exerted upon the crank-shaft will compensate or counterbalance one another, excepting, however, the immaterial differences due to the finite length of the connecting-rods, or, in other words, the resultant of the forces acting in one direction must be equal to the resultant of the forces acting in the opposite direction, and the resultants of both these groups of forces must be in a straight line. Hence if the distance between the cylinder centers, the length of the crank-arms, the weight of the movable elements, and particularly also the angle formed by the various cranks are determined in accordance with the statements and relations hereinbefore given neither a displacement of the engine in the direction of motion of the piston-rods nor a tilting of the same in the plane of said rods can take place; but when the piston-rods of a plurality of cylinders are connected with the same crank and said piston-rods perhaps connected by cross-head it is necessary in determining the weights of the moving elements and the relative position of the cranks to take into consideration the distance of the centers of gravity measured at a right angle to the direction of the stroke of the pistons of different groups of cylinders instead of the distance between the cylinder centers.

It has hereinbefore been assumed that the weights and the angle formed by the cranks of two of the cylinders (outer or intermediate) are given, and that from these the required weights and the angle formed by the cranks of the other two cylinders can be determined; but the problem may also be solved when the weights, the angle formed by the cranks, the length of the crank-arms, and the distance between the centers of an outer and intermediate cylinder are given.

In an engine constructed as hereinbefore set forth it is possible not only to counterbalance the forces exerted upon the crank-shaft in the direction and plane of the piston-stroke, but also in a plane at right angles thereto passing through the center of the crank-shaft, Figs. 8 and 9, which is also a peculiar property in an engine constructed according to my invention. In order that this may be understood, it is necessary to point out that the position of the cranks is dependent solely upon the relations of the reciprocating masses when the angle formed by two of the cranks is known or given. When, therefore, the weights reduced to the circle described by the crank-pin and which act upon the several cranks at right angles to the direction of the stroke, particularly the weights of the crank-bearings, connecting-rods, and crank-arms, bear exactly the same relation to one another as the moving elements of the cylinders which act upon said cranks in the direction of the stroke, the forces exerted at right angles to the direction of said moving elements in a plane passing centrally through the crank-shaft will also balance one another.

All of the weights moving horizontally (in a vertical engine) may, in accordance with previous designation, be indicated by w P I, w P II, w P III, and w P IV, and according to the formulæ 8 and 9 the relative angles formed by and between the crank-arms will be found from the following equations:

$$(16)\quad \text{Sin. } \alpha = \text{sin. } \gamma \frac{\frac{1}{3}\, w \text{ P III}}{w \text{ P II}} = \text{sin. } \gamma \frac{\frac{1}{3}\text{ P III}}{\text{P II}},$$

$$(17)\quad \text{Sin. } \beta = \text{sin. } \gamma \frac{\frac{1}{3}\, w \text{ P IV}}{w \text{ P I}} = \text{sin. } \gamma \frac{\frac{1}{3}\text{ P IV}}{\text{P I}},$$

the same angles being obtained as before. According to formulæ 6 and 7 I moreover obtain the weights acting horizontally upon the cranks, and which may be designated by P′ I and P′ II, as follows:

$$(18)\quad \text{P}'\text{ I} = \sqrt{(\tfrac{2}{3}\, w \text{ P III})^2 + (\tfrac{1}{2}\, w \text{ P IV})^2 + \tfrac{4}{9}\, w \text{ P III } w \text{ P IV cos. } \gamma},$$

$$(19)\quad \text{P}'\text{ I} = w \sqrt{(\tfrac{2}{3}\text{ P III})^2 + (\tfrac{1}{3}\text{ P IV})^2 + \tfrac{4}{9}\text{ P III P IV cos. } \gamma},$$

$$(20)\quad \text{P}'\text{ I} = w \sqrt{(\tfrac{2}{3}\text{ P IV})^2 + (\tfrac{1}{3}\text{ P III})^2 + \tfrac{4}{9}\text{ P III P IV cos. } \gamma}.$$

Consequently we obtain

$$(21)\quad \text{P}'\text{ I} = w \text{ P I},$$

$$(22)\quad \text{P}'\text{ II} = w \text{ P II},$$

thus proving the assertion above made. Hence if the forces that act in a horizontal direction upon the cranks bear the same relation to one another as those which act upon said cranks in a vertical direction and when these relations correspond with the laws above set down then the reactive forces will be perfectly balanced, not only in planes passing horizontally and vertically through the crank-shaft, but in any other plane passing through the center of the crank-shaft.

I have deemed it unnecessary to describe in detail.

In Figs. 7 and 8, which illustrate a four-crank steam-engine constructed in accordance with this invention and in accordance with the balance diagram Figs. 8 and 9, F indicates the main frame; I, II, III, and IV, the cylinders; R, the piston-rods; r, the connecting-rods; S, the crank-shaft; 1, 2, 3, and 4, the four cranks, respectively, and P the steam-supply pipe.

The herein-described method may also be used in the balancing of other forces than those referred to—namely, those forces exerted by the valve-gear or other moving elements. This can be effected in two ways, no account being taken of the slight errors due to the finite length of the eccentric-rods. If, for example, the centers of the slide-valves lie in the same plane as the piston-rods, the weight of the moving elements of the valve-gearing can be taken into consideration when the angles of the cranks and the weights acting upon the same are determined, whereby the forces exerted by the valve-gear can be balanced simultaneously with the forces exerted upon the cranks. If, however, the slide-valves or rods lie in a different plane from that of the piston-rods, it will only be necessary to so arrange that the distances between the valve-rods, the weights of the moving parts of the valve-gear, the radii, and angles of the eccentrics shall have the same relation to one another as in balancing the moving elements of the cylinders and the cranks. If, for instance, the distances between the valve-rods are equal to the distances between the cylinder centers, and if all the eccentrics have an equal throw and an equal angle of lead, it is only necessary to determine the weights of the moving elements of the valve-gear in the same manner as that resorted to for the determination of the weights of the moving elements of the cylinders. Should some of the valves differ, it will in most cases still be possible to balance the forces of their moving elements by choosing the other or remaining factors accordingly. In order, however, to perfectly balance the said forces, it is necessary that the centers of gravity be situated in the centers of the slide-rods and that the latter lie in one and the same plane.

In Fig. 9 I have shown a balance diagram of an engine in which I have given, first, the distances *a a a* between the cylinder centers; second, the total weight of the moving parts for cylinder III—viz., P_3 equals twelve thousand three hundred and seventy pounds; third, the total weight of the moving parts of cylinder IV—viz., twelve thousand six hundred and seventy pounds; fourth, the angular relation of cranks for cylinders III and IV, the latter leading the former by one hundred and twenty degrees, Fig. 10; fifth, assumed that all the cranks have the same stroke forty-eight seconds.

In accordance with the mode of determination hereinabove explained I find the total weights of the moving parts for cylinders I and II and the angular relation of their cranks as follows: The weights required to balance the forces exerted by the moving weights of cylinder III are $\frac{2a}{3a}$ of P_3 at crank No. 2 diametrically opposite crank No. 3, and $\frac{a}{3a}$ of P_3 at crank No. 1 diametrically opposite crank No. 3. Similarly the weights required to balance the forces exerted by the moving elements of the cylinder IV are $\frac{2a}{3a}$ of P_4 at crank No. 1 diametrically opposite crank No. 4, and $\frac{a}{3a}$ of P_4 at crank No. 2 diametrically opposite crank No. 4. Combining the above and separating crank-cricle No. 1 from circle No. 2 I obtain two weights $\frac{1}{3} P_3$ and $\frac{2}{3} P_4$ on No. 1 crank-circle and two weights $\frac{2}{3} P_3$ and $\frac{1}{3} P_4$ on crank-circle No. 2. Weight of moving parts for crank No. 1, R_1 equals one thousand two hundred and ninety pounds. (Valve-gear neglected.) Weight of moving parts for crank No. 2, R_2 equals seven thousand one hundred and thirty-eight pounds. (Valve-gear neglected.) By the parallelogram of forces the resultant R_1 will be found to be $\frac{1}{3} P_3$ and $\frac{2}{3} P_4$, which determine the position of crank No. 1 and the weight of the moving parts of cylinder I. Similarly R_2 determines the position of crank No. 2 and the weight of the moving parts of cylinder II. The angular relation of the four cranks and the weights acting on said cranks are shown in Fig. 10, the weights of the principal moving parts having been considered only. If the forces exerted by the valve-gears be considered, then we must find the weights Q_1 and Q_2, acting on No. 1 and No. 2 cranks, which balance the whole system of valve-gears, then find the resultant P_1 of Q_4 and R_1 and the resultant P_2 of Q_2 and R_2. These resultants give the final positions of cranks Nos. 1 and 2 and the final weights of the moving parts of cylinders I and II, Fig. 10.

Referring to Fig. 9, A is the ahead valve-gear for cylinder I, its weight being one thousand six hundred and eighty pounds at seven and one-half seconds travel. B is the astern valve-gear for said cylinder I, its weight being one thousand one hundred and twenty pounds at seven and one-half seconds travel, and so on. OA, Fig. 10, is the angle of the ahead eccentric and OB the angle of the astern eccentric for cylinder I relatively to crank No. 1, whose approximate position has been found, as hereinabove indicated. OC is the angle of the ahead eccentric and OD the angle of the astern eccentric for cylinder IV relatively to crank No. 4, and similarly for the others. The positions of these eccentrics relatively to their respective cranks are found in the ordinary way when the lap, lead, and travel of the valves are known. The actual position of the centers of the eccentrics will of course be on the circumference of a circle whose diameter is equal to the stroke of said eccentrics, the line OA OB OC, &c., passing through these centers. It is, however, sufficient for the purposes of this description that the angles of the lines OA OB OC, &c., relatively to the angles of cranks Nos. 1 2, &c., are known, at the same time bearing in mind that the actual weights of the valve-gears or their equivalents at their respective strokes will have to be altered to their equivalent weights at the stroke of the cranks before they can be combined with the main weights of the engine to find the final weights of the moving parts for cylinders I and II. It will be noted that the valves for cylinders III and IV are at the back of the engine and are respectively actuated by levers from the eccentric-rods FG and CD, Fig. 9, so that, referring again to Fig. 10, OH is the vertical angle of eccentric that actuates the valve for cylinder III and OE the vertical angle of eccentric that actuates the valve for cylinder IV. OH is exactly opposite OF, the actual ahead eccentric for cylinder III, and is exactly opposite OC, the actual eccentric for cylinder IV.

Referring now to Fig. 9, find by the principles of the lever the weights at Nos. 1 and 2 engine centers which together will equal B. Thus 1,319.5 pounds at No. 1 center and 199.5 pounds (which may be called "negative," since it is diametrically opposite B) at No. 2 center are equivalent to a single weight B equals eleven hundred and twenty pounds, and similarly for all the other valve-gears. The column of figures on the right of Fig. 9 indicate the weights at No. 1 center, and the column of figures on the left indicate the weights at No. 2 center, thus found. All these weights R and S are now referred to the same stroke as the engine-cranks. Thus 1,319.5 at seven-and-one-half-inch stroke is at forty-eight-inch stroke equivalent to $206=b'$, and 199.5 at seven-and-one-half-inch stroke is at forty-eight-inch stroke equivalent to $31.2=b$, &c. 306 at six-inch stroke is at forty-eight-inch stroke equivalent to $38.2=i'$, and 1,664 at six-inch stroke is at forty-eight-inch stroke equivalent to $208=i$. I thus obtain a series of weights around No. 1 crank-circle and a series of weights around No. 2 crank-circle, which are together equivalent to the weight of all the valve-gears, their positions around said crank-circle being indicated by the symbols A E F B I G J C H D. Now find by the polygon of forces the single weight Q_1 which balances one of said series of weights and the single weight Q_2 which balances the other. Then find the resultant by the parallelogram of forces of Q_1 and R_1 as hereinbefore set forth, which gives P_1 equals seven thousand and thirty-five pounds, which is the final weight for the moving parts of cylinder I. Find the resultant of Q_2 and R_2, which gives P_2 equals seven thousand four hundred and twenty pounds, the final weight for the moving parts of cylinder II. The final positions of cranks Nos. 1 and 2 are also determined by the positions of P_1 and P_2, whereby an angular relation of cranks such as shown in Fig. 10 is obtained—*i. e.*, the angle between Nos. 1 and 2 cranks, sixty-one degrees; that between Nos. 1 and 3, eighty-eight and one-half degrees; that between Nos. 3 and 4, one hundred and twenty degrees, and that between Nos. 4 and 1, two hundred and ninety and one-half degrees, the total weights acting on said cranks 1 2 3 4 being seven thousand and thirty-five pounds, seven thousand four hundred and twenty pounds, twelve thousand three hundred and seventy pounds, and twelve thousand six hundred and seventy pounds, respectively.

By the described invention the supports for the engine are not injuriously affected, so that the loosening of the same need not be feared, and consequently vibrations are not communicated to the vessel itself. The location of the engines in a vessel may be chosen at will, which is impossible with engines as now constructed. The number of revolutions of the crank-shaft within a given time may also be chosen at will without danger of undue vibrations of the vessel when a given number of revolutions within such time is exerted, as is the case with the engines now in use. Finally, it is possible to use engines constructed according to my invention in the upper stories of buildings where heavy foundations cannot be provided.

Having thus described my invention, what I claim as new therein, and desire to secure by Letters Patent, is—

1. In steam or like motive-power engines, the combination with the cylinders arranged side by side with their longitudinal axes at predetermined distances apart and the moving elements of said cylinders, namely, their pistons and parts reciprocating therewith; of a shaft having four cranks acted upon by the said moving elements and set at different angles, the angular relation of said four cranks varying in accordance with and being determined by their length, the distances between them, and the weights of the aforesaid moving elements, to balance the reaction forces engendered by the weight of said parts and acting upon the crank-shaft in planes perpendicular to each other, for the purpose set forth.

2. In a steam or like motive-power engine, the combination with cylinders of varying diameter arranged side by side with their longitudinal axes at predetermined distances apart, and the moving elements of said cylinders, namely, their pistons and parts reciprocating therewith; of a shaft having four cranks acted upon by the said moving elements and set at different angles, the angular relation of said four cranks varying in accordance with and being determined by their length, the distances between them, and the weights of the aforesaid moving elements to balance the reaction forces engendered by the weight of said parts and acting upon the crank-shaft in planes perpendicular to each other, for the purpose set forth.

3. In a steam or like motive-power engine, the combination with cylinders of varying diameter arranged side by side with their longitudinal axes at predetermined distances apart, the cylinders of greater diameter between those of smaller diameter, and the moving elements of said cylinders, namely, their pistons and parts reciprocating therewith; of a shaft having four cranks acted upon by the said moving elements and set at different angles, the angular relation of said four cranks varying in accordance with and being determined by their length, the distances between them, and the weights of the aforesaid moving elements, to balance the reaction forces engendered by the weight of said parts and acting upon the crank-shaft in planes perpendicular to each other, for the purpose set forth.

4. In a steam or like motive-power engine, the combination with the cylinders arranged side by side with their longitudinal axes at predetermined distances apart, the moving elements of said cylinders, namely, their pistons and parts reciprocating therewith, and the valve-gears; of a shaft having four cranks acted upon by the said moving elements and valve-gears and set at different angles, the angular relation of the four cranks varying in accordance with and being determined by

their length, the distances between them, and the weights of the aforesaid moving elements, to counterbalance the reaction forces engendered by said moving elements and acting upon the crank-shaft in planes perpendicular to each other, for the purpose set forth.

In testimony that I claim the foregoing as my invention I have signed my name, in presence of two witnesses, this 22d day of August, 1895.

ERNST OTTO SCHLICK.

Witnesses:

MAX LEMCKE,

E. PH. MUMMENHOFF.