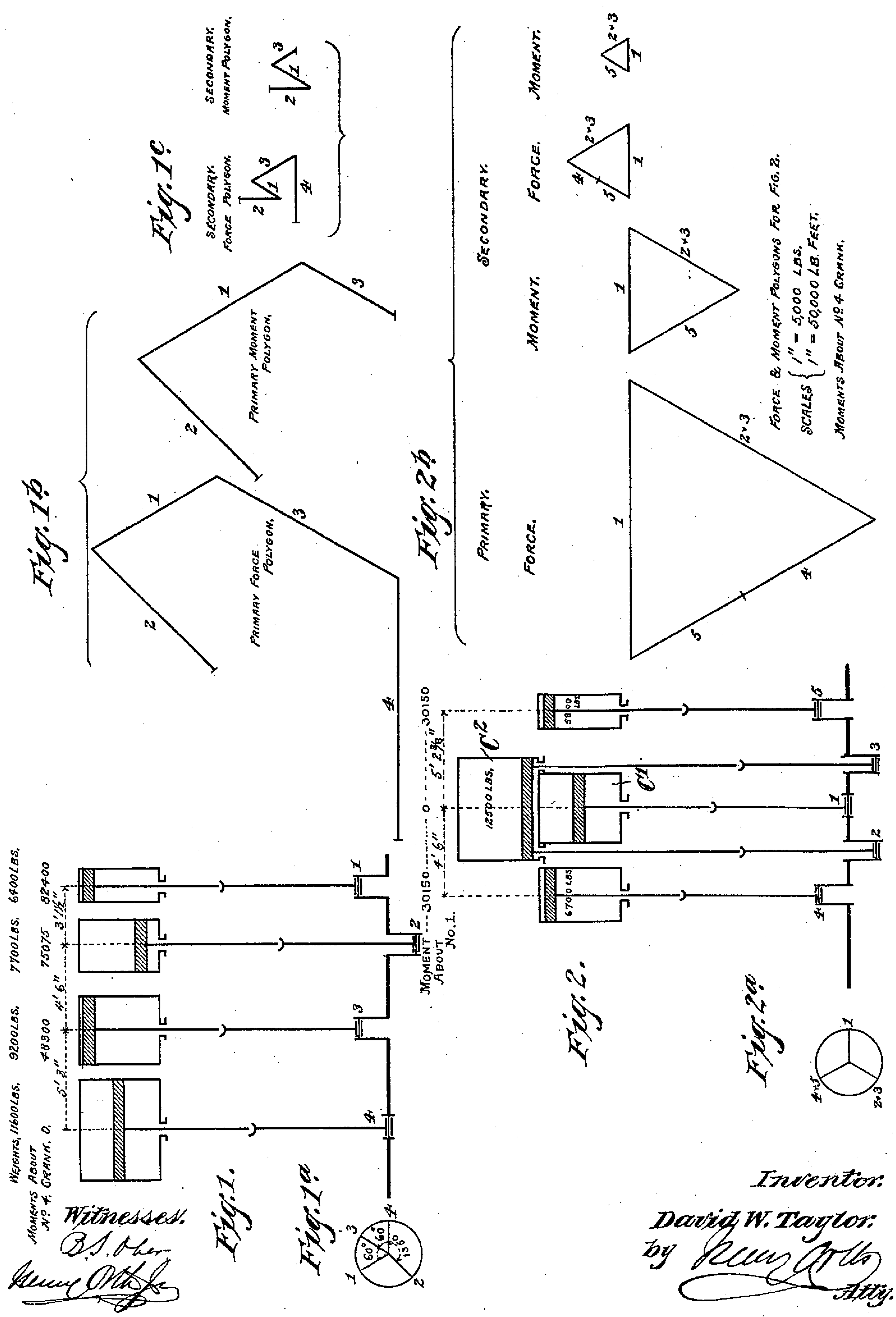
No. 614,674. **Patented Nov. 22, 1898.**

D. W. TAYLOR.
STEAM ENGINE.

(Application filed Dec. 31, 1897.)

(No Model.) 3 Sheets—Sheet I.



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THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

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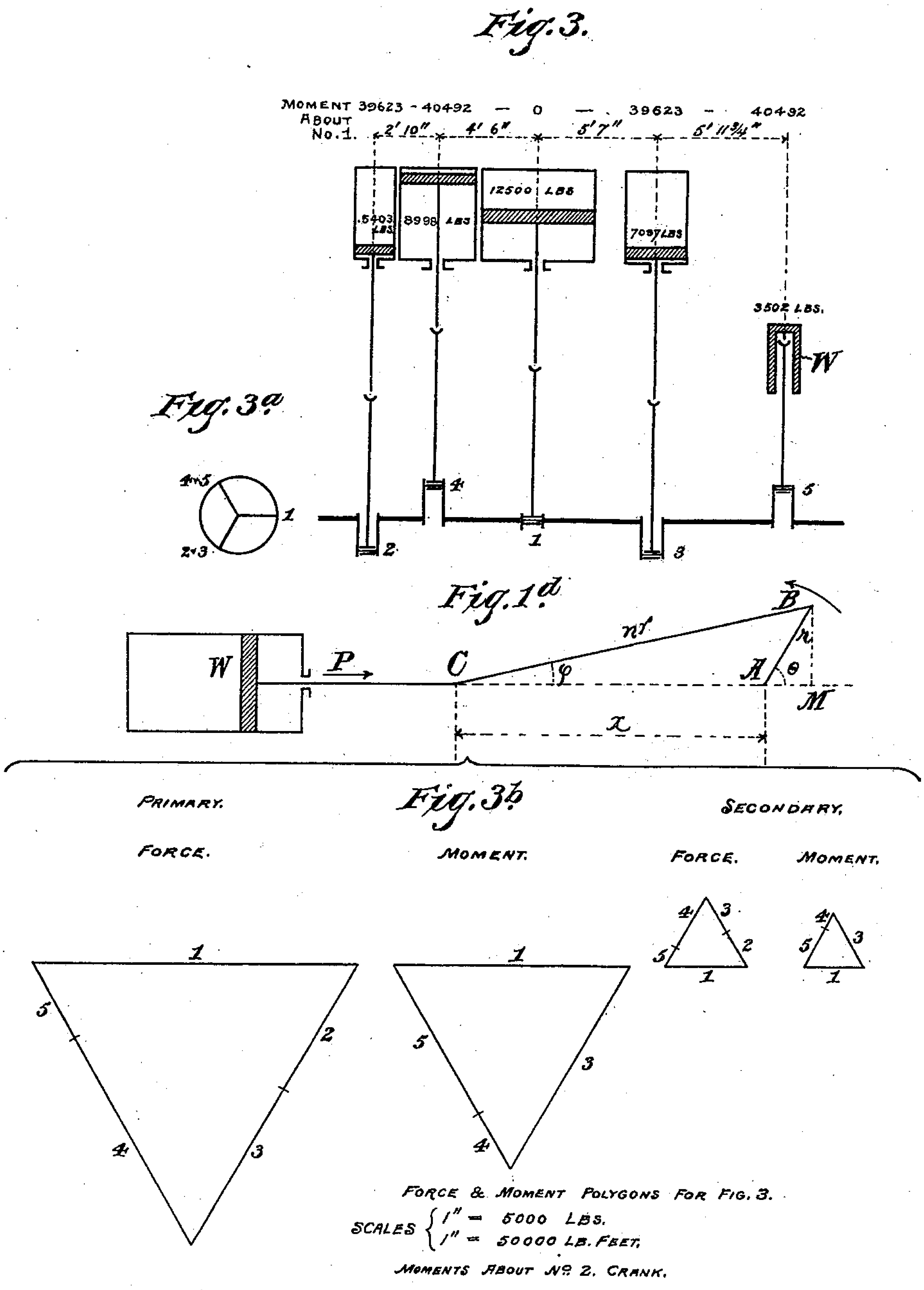

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Fig. 4.

Fig. 4a

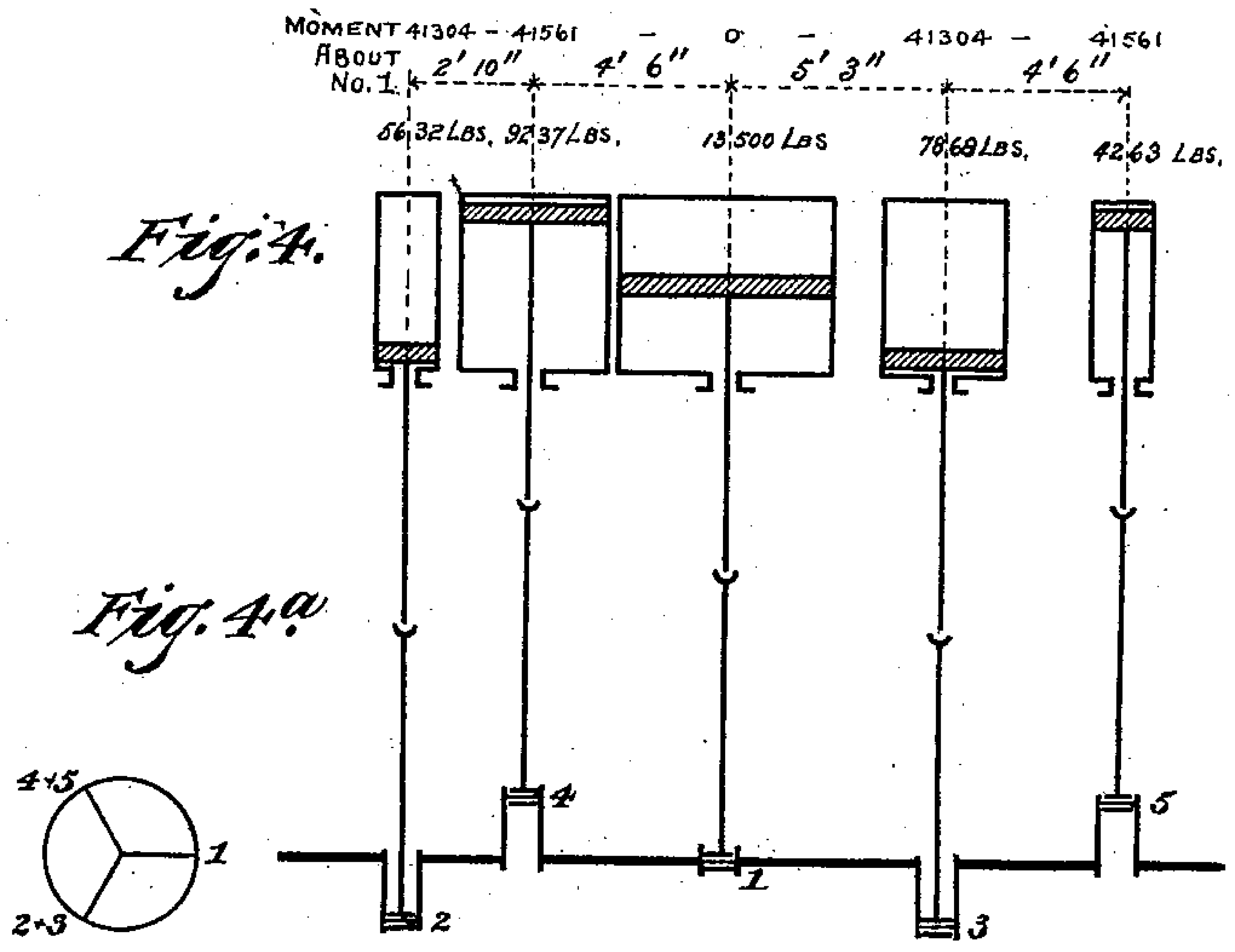
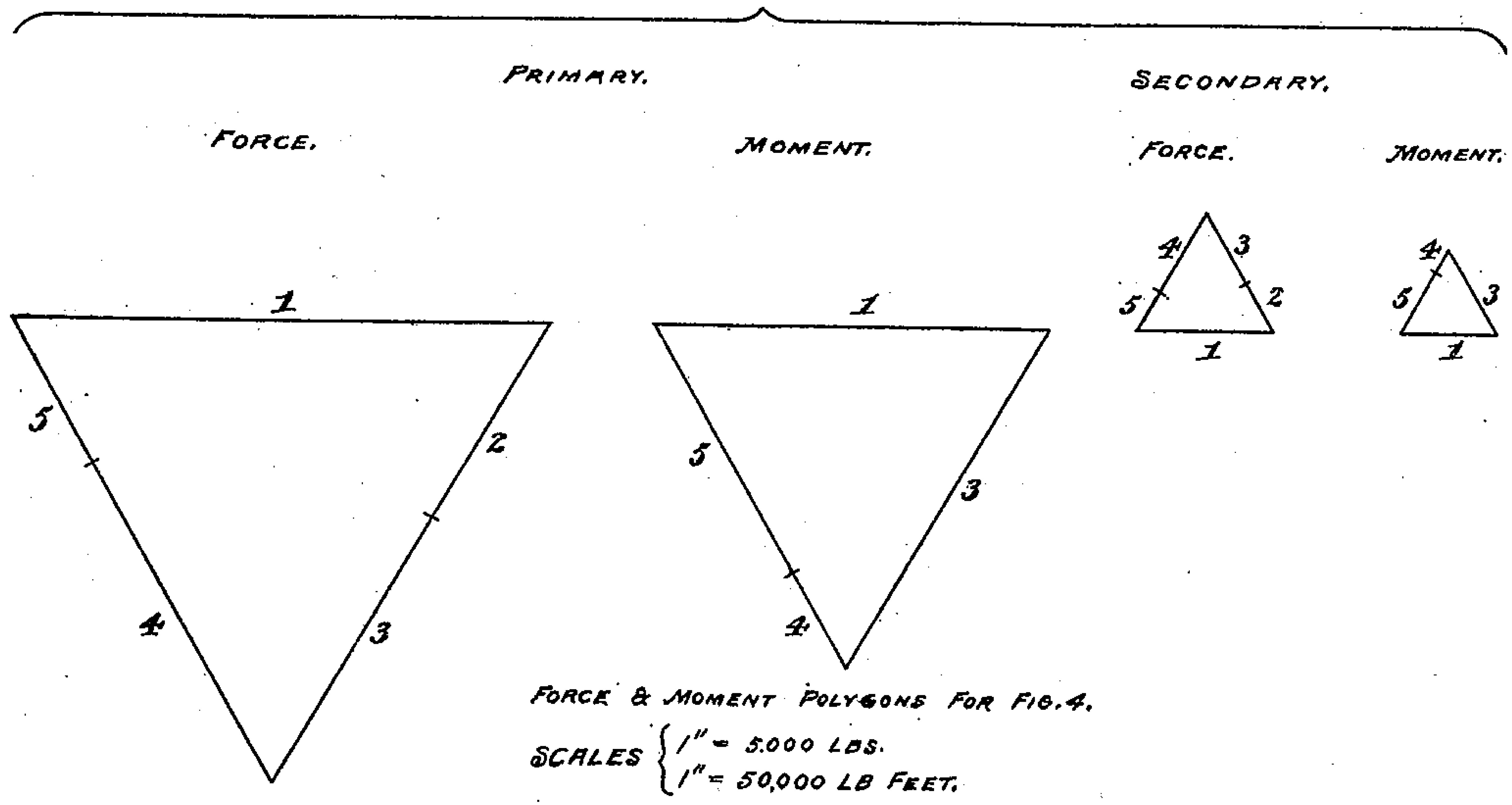


Fig. 4b



FORCE & MOMENT POLYGONS FOR FIG. 4.

SCALES { 1" = 5.000 LBS. / 1" = 50,000 LB FEET.

MOMENTS ABOUT No. 2. CRANK.

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UNITED STATES PATENT OFFICE.

DAVID W. TAYLOR, OF WASHINGTON, DISTRICT OF COLUMBIA, ASSIGNOR TO THE YARROW SCHLICK & TWEEDY SYSTEM, LIMITED, OF LONDON, ENGLAND.

STEAM-ENGINE.

SPECIFICATION forming part of Letters Patent No. 614,674, dated November 22, 1898.

Application filed December 31, 1897. Serial No. 664,890. (No model.)

To all whom it may concern:

Be it known that I, DAVID W. TAYLOR, a citizen of the United States of America, residing at Washington, District of Columbia, have invented certain new and useful Improvements in Steam-Engines; and I do hereby declare the following to be 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 and figures of reference marked thereon, which form a part of this specification.

As is well known, when the shaft of a steam or like motive-power engine is revolved by the action thereon of a force exerted by the piston of the working cylinder an unbalanced force is set up in opposition to the direction of motion or acceleration of such piston and parts reciprocating therewith. The pressure of the steam upon the piston and cylinder-head is equal if the piston were immobolized. Hence the forces exerted upon said piston and cylinder-head are balanced and transmitted to the engine-framing through such piston and cylinder-head. As soon, however, as the piston and parts connected therewith are allowed to move a certain portion of the pressure upon said piston is absorbed or converted into work in producing motion and acceleration of motion and is therefore not transmitted beyond the moving elements to the engine-framing. On the other hand, when the movements of the piston and parts connected therewith are retarded a force greater than that exerted by the steam upon the piston is transmitted to the engine-framing. Inasmuch as the direction of motion of the piston is reversed at the end of each stroke, such piston and necessarily the parts reciprocating therewith are constantly subjected to acceleration and retardation, and for each working cylinder, when there is more than one, an unbalanced force is developed whose direction and magnitude at any moment or instant are dependent upon the direction and magnitude of acceleration of the piston at that instant. In a multiple-cylinder engine the group of unbalanced forces thus set up can by well-known rules and laws of mechanics be resolved into a single force and couple.

In order that my invention may be clearly understood, I will describe the derivation of the well-known formula expressing the value of an unbalanced force due to a reciprocating weight of known amount connected with a crank of known length revolving at a uniform definite speed.

Given a piston-rod of a weight W, connected by a rod C B of a length $n r$ to a crank A B of a length r, revolving about a crank-shaft center A and making at a given moment an angle θ with a line C A, produced from the axis of the cylinder and the angle B C A, denoted by φ. Let A C be denoted by x, then

$$x = AC = CM - AM = CB\cos.\varphi - AB\cos.\theta$$
$$= n r \cos.\varphi - r\cos.\theta$$
$$BM = CB\sin.\varphi = AB\sin.\theta.$$
$$\therefore\ n r \sin.\varphi = r\sin.\theta$$
$$\sin.\varphi = \frac{\sin.\theta}{n}.$$

Whence

$$\cos.\varphi = \sqrt{1-\sin.^2\varphi} = \frac{1}{n}\sqrt{n^2-\sin.^2\theta}.$$

Whence

$$x = r\left(\sqrt{n^2-\sin.^2\theta} - \cos.\theta\right).$$

Differentiating x with respect to time t in order to obtain the velocity of the point C, we have

$$\frac{dx}{dt} = r\left(\frac{\sin.2\theta}{2(n^2-\sin.^2\theta)^{\frac{1}{2}}} + \sin.\theta\right)\frac{d\theta}{dt}.$$

$\frac{d\theta}{dt}$ is the uniform angular velocity of rotation of the crank. The acceleration of the point C is obtained by differentiating with respect to time t the expression for velocity $\frac{dx}{dt}$ and we obtain

$$\frac{dx}{dt} = r\left(\frac{n^2\cos.2\theta + \sin.^4\theta}{(n^2-\sin.^2\theta)^{\frac{3}{2}}} + \cos.\theta\right)w^2.$$

Now $\cos.\theta + \frac{n^2\cos.2\theta\ \sin.^4\theta}{(n^2-\sin.^2\theta)^{\frac{3}{2}}}$ is very approximately equal to $\cos.\theta + \frac{\cos.2\theta}{n}$. The maximum deviation for $\theta = 90°$ where the approximate formula when $n=4$ gives .2500, while the exact value is .2582. The maximum value of the expression being 1.2500 (for $\theta = 0$) it follows that the maximum deviation of .0082 is less than two-thirds of one per cent. of the maximum value. This is for $n=4$, corresponding to the shortest length of connecting-rod commonly used. For longer connecting-rods the deviation of the approximate formula from the truth rapidly decreases, the maximum deviation being about one-eighth of one per cent. of the maximum for $n=7$ and one-thirtieth of one per cent. of the maximum for $n=10$. W denoting the weight accelerated, the force to produce acceleration is measured by the product of its mass, or $\frac{W}{g}$, into the acceleration in feet per second, whence the very approximate formula

$$P = \frac{W}{g}\frac{d^2 x}{d t^2} = \frac{W}{g} w^2 r \left(\cos.\ \theta + \frac{\cos.\ 2\ \theta}{n}\right),$$

in which P indicates force in pounds, W weight in pounds, g the acceleration due to gravity in feet per second, w the angular velocity in units of circular measure per second of the crank-arm supposed to revolve uniformly, r the length of the crank-arm in in feet, and θ the angle between the crank-arm and the line joining the center of the shaft with the cylinder-axis.

The above expression for P is made up of two terms

$$\frac{W}{g} w\ r \cos.\ \theta \text{ and } \frac{W}{g} w^2\ r \left(\frac{\cos.\ 2\ \theta}{n}\right).$$

If the connecting-rod were of infinite length, we should have $n = \infty$ and the second term would become zero.

For the connecting-rods of finite length used in practice the first term, which is independent of the length of the connecting-rod, is more important, its maximum value in practice being seldom less than four times that of the second term. That part P denoted by $\frac{W}{g} w^2 r \cdot \cos.\ \theta$ is conveniently designated a "primary" force and that denoted by $\frac{W}{g} w^2 r \left(\frac{\cos.\ 2\ \theta}{n}\right)$ a "secondary" force. It is evident that the secondary force has a maximum value $\frac{W}{g} w^2 r \times \frac{1}{n}$, while the primary force has a maximum value $\frac{W}{g} w^2 r$. The maximum value of the secondary force is then but $\frac{1}{n}$th the maximum value of the primary force; also, since the secondary force varies, as cos. 2 θ, its period is but one-half that of the primary force which varies, as cos. θ.

When several cranks are used on a shaft, the several inertia forces combined by the well-known laws of mechanics are equivalent at any instant to a single force and a couple. It is convenient to analyze the moments of the inertia forces corresponding to the various cranks into primary and secondary moments due to the primary and secondary forces, respectively.

It is further well known that if for a number of cylinders having their axes parallel from a given point as origin a line is drawn parallel with the first crank, such line representing, on a fixed scale, the reciprocating weight acting upon such crank, a second line can be drawn from the terminal of the first and corresponding to the second crank and weight acting thereon, and so on for each crank, and a polygon obtained of as many sides as there are cranks, with the property that a closing-line connecting the terminal of the last side with the origin represents in direction a crank equal to those of the actual engine and in length a reciprocating weight connected with and acting upon said crank that will neutralize the unbalanced primary force. In a similar manner the moments of the reciprocating parts about some point of the axis of the crank-shaft can be calculated and a second polygon drawn having sides parallel to cranks and proportional to the moments, the closing-line of such polygon representing a crank in direction and in length the moment of a reciprocating weight connected with and acting upon said crank such as to neutralize the moment of the engine about the chosen point of the axis of the crank-shaft. These polygons are called the "primary force" and the "primary moment" polygons, respectively. If these are closed initially—that is to say, if the terminal of the line representing the last crank joins the beginning of the line representing the first crank—then the resultant primary force and moment are equal to zero and the engine is balanced as regards primary forces.

It is also a fact, though not so well known, that secondary force and moment polygons having properties similar to the primary force and moment polygons can be drawn. Each side of these secondary polygons will be $\frac{1}{n}$th the length of their corresponding primary polygons on the same scale and must make with a fixed direction in space double the angle of the corresponding sides of the primary polygon.

To illustrate these known facts, reference is had to Figure 1 of the drawings, wherein I have diagrammatically illustrated a four-crank unbalanced engine, Fig. 1[a] illustrating the angular relation of the cranks, Fig. 1[b] the primary force and moment polygons, and Fig. 1[c] the secondary force and moment polygons.

In the engine illustrated it is assumed that the length of the connecting-rod is four times that of the cranks, so that the sides of the secondary polygons will be one-fourth the corresponding sides of the primary polygons, moments being taken about the center of No. 4

crank, the sides of the moment polygons corresponding to said No. 4 crank being zero. The question whether or no a given engine is balanced as regards the primary or secondary forces or moments is readily determined by drawing the corresponding polygons and observing whether they are closed or not, and if closed the engine will be balanced.

Owing to the injuries and objectionable effects of unbalanced steam and like motive-power engines, many attempts have been made to balance the injuriously-acting forces, and various methods are known whereby a partial or complete balance may be obtained in so far as certain classes of engines are concerned, as four-crank engines, such as illustrated in Fig. 1, or engines the number of cylinders of which is a multiple of three. So far as I know there is, however, no method known by which the primary and secondary forces and moments generated or set up in a five-crank engine can be balanced, and my invention consists in the provision of means for balancing these forces and moments in this class of engines, reference being had to Figs. 2 to 4^b of the accompanying drawings, Figs. 2, 3, and 4 illustrating, diagrammatically, five-crank engines in which the arrangement of the cylinders is varied, Figs. 2^a, 3^a, and 4^a illustrating the angular relation of the cranks of said engines, while Figs. 2^b, 3^b, and 4^b illustrate the force and moment polygons of the engines shown in Figs. 2, 3, and 4, respectively, these polygons being resolved into equilateral triangles showing them closed.

In order to balance a five-crank engine in accordance with my invention, the cranks must be equal, and one of them may drive a reciprocating weight, Fig. 3. The greatest weight must act on the middle crank, which I will call the "first" crank. The second and third cranks are parallel and are arranged on opposite sides of the first crank and at an angle thereto of one hundred and twenty degrees. The sum of the reciprocating weights acting on the intermediate cranks, which I will call the "second" and "third" cranks, must be equal to the weight acting upon the first crank, and the moment of the reciprocating weight on the second crank about the first must be the same as that of the third. The outer cranks, which I will call the "fourth" and "fifth" cranks, are parallel and arranged on opposite sides of and at an angle thereto and to the second and third cranks of one hundred and twenty degrees. The sum of the reciprocating weights acting on the said fourth and fifth cranks must be equal to the reciprocating weight acting on the first crank and the moment of the reciprocating weight of the fourth crank about the first must be the same as that of the fifth crank, or, in other words, the moments of the two weights of each pair of cranks 2 3 and 4 5 about crank 1 must be equal—that is to say, the product of the reciprocating weight on the forward crank of a pair, multiplied by its distance from the middle crank 1, must be equal to the product of the reciprocating weight acting on the after crank of a pair multiplied by its distance from the middle crank 1, the distance between cranks being measured in each case from center to center of the crank-pins.

The relative arrangement of the cylinders in an engine balanced in accordance with my invention, as just set forth, may be varied. Thus in Fig. 2 I have shown an engine in which the second and third cranks are equidistant from the first, cylinders C′ and C^2 being arranged in tandem, the piston of C^2 being connected to the second and third cranks. In the engine, Fig. 3, there are also but four cylinders, the fifth crank driving a reciprocating weight, the cranks being arranged at different distances from one another, while the engine shown in Fig. 4 has five cylinders, the distance between cranks 5 and 3 and 1 and 4 being the same. It will thus be seen that the distances between the cylinder axes or the cranks is not dependent upon the forces acting upon the cranks nor upon the angular relation of said cranks, nor is it necessary that there should be a separate cylinder for each crank. Of course for the sake of economy in space, and especially the arrangement of cylinders, Fig. 2 is a very good one, though that shown in Fig. 3 is perhaps more practical, while in any arrangement the cylinders should be placed as near together as possible.

It is obvious from what has been said that the gist of my invention lies in the use of five cranks having the described definite angular relation and in the distribution, as set forth, of the reciprocating weights and moments acting upon said cranks. On the other hand, instead of connecting two cranks with the piston of one cylinder any number of pistons may act upon a single crank, provided the total reciprocating weight acting upon such crank has the magnitude and amount, as above prescribed.

By the means described I can abolish or neutralize both primary and secondary forces, as well as corresponding moments—a result not attainable by any method now known to me, unless it be in a five-crank engine and in accordance with my invention, as hereinbefore described in detail. In three-crank engines primary or secondary forces can be balanced. In four-crank engines primary forces and moments or primary and secondary forces can be balanced, but nothing more. Only when five cranks are used does it become possible to completely balance both primary and secondary forces and primary and secondary moments.

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

1. In a steam or like motive-power engine, the combination with the crank-shaft having cranks 1, 2, 3, 4 and 5, of uniform length, the cranks 2 and 3 on opposite sides of crank 1

being parallel and at an angle of one hundred and twenty degrees ahead of crank 1, cranks 4 and 5 also on opposite sides of crank 1 being likewise parallel and at an angle of one hundred and twenty degrees behind crank 1, of the cylinders arranged with their axes in the same plane and the reciprocating parts of the engine, the weights of which distributed so that the greatest weight will act upon crank 1, the sum of the weights acting upon cranks 2 and 3 and upon cranks 4 and 5 respectively being equal to the weight acting upon said crank 1, the moment of the weight acting upon crank 2 about crank 1 being equal to the moment of the weight acting upon crank 3 about crank 1, and the moment of the weight acting on crank 4 about crank 1 being equal to the moment on crank 5, substantially as set forth.

2. In a steam or like motive-power engine, the combination with the crank-shaft having cranks 1, 2, 3, 4 and 5, of uniform length, cranks 2 and 3 on opposite sides of crank 1 being parallel and at an angle of one hundred and twenty degrees ahead of said crank 1, cranks 4 and 5, also on opposite sides of crank 1 being likewise parallel and at an angle of one hundred and twenty degrees behind said crank 1, of the cylinders arranged with their axes in the same plane, the reciprocating parts of the engine, the weights of which so distributed that the greatest weight will act upon crank 1 the sum of the weights acting upon cranks 2 and 3 being equal to the weight acting upon said crank 1, the moment of the weight acting upon crank 2 about crank 1 being equal to the moment of the weight acting upon crank 3 about said crank 1, and a dead weight set in motion by crank 5, the sum of the weights acting upon cranks 4 and 5 being equal to the weight acting upon crank 1, and the moment of the weight acting upon crank 4 about crank 1 being equal to the moment of the weight acting upon crank 5 about said crank 1, substantially as and for the purpose set forth.

In testimony that I claim the foregoing as my invention I have signed my name in presence of two subscribing witnesses.

DAVID W. TAYLOR.

Witnesses:
R. G. SKERRETT,
W. A. DOBSON.