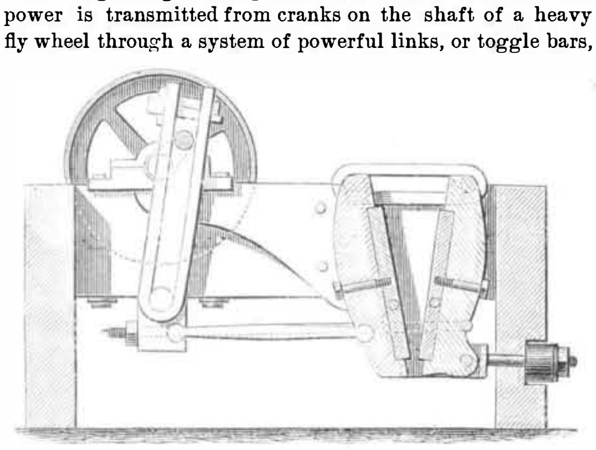
compose the levers at a right angle with the rod next to it. This lever is attached to the periphery of the wheel by the hinge joint, B, provided with the shoulder, to prevent its falling into any other than a right line from the center of the circumference of the wheel. The levers are furnished at their outer extremities with a bucket, or receiver, the bottom of which is sufficiently broad to retain the ball, C. The balls remain in the buckets till the buckets come into the position of the lever, D, when they are expected to roll out of the buckets on to the inclined plane, and by their own gravity roll to the other end of the inclined plane, ready to be again taken into the buckets.

QUARTZ CRUSHER.

In machines designed for breaking stones, crushing ores, etc., simplicity is absolutely essential. Pride and poverty are fully as congenial as rude work with complication in mechanism. The parts of such machines should therefore be few and massive, and be so put together thas even common laborers may be able to keep them in running order.

Messrs. Varney & Rix, of San Francisco, Cal., have patented a machine which seems, so far as simplicity is concerned, to answer the requirements of the case.

Our engraving is a representation of this machine. The power is transmitted from cranks on the shaft of a heavy fly wheel through a system of powerful links, or toggle bars,



to pivoted jaws, which thus approach each other with great force at each revolution of the fly wheel, compressing the quartz and thus crushing it. The general principle of the mastication of food by the jaws of animals is very nearly approached in this machine.

ACTION OF THE RECIPROCATING PARTS OF STEAM ENGINES, AND ITS INFLUENCE ON THE PROBLEM OF HIGH PISTON-SPEED.

Read before the Polytechnic Club of the American Institute, by Chas. T. Porter.

Your attention is invited to a proposition, which, on its bare statement, will probably strike many persons as absurd. It is, that a reciprocating engine is, with respect to the line of centers, identical with a rotary engine; reciprocation is, in the line of motion, identical with rotation; the reciprocating parts of an engine, at the instant when the direction of their motion is reversed, exert a force, which is precisely the same centrifugal force that would be exerted by them continually if they were revolving with the crank; so that reciprocation may properly be defined to be rotation in a straight line.

I am well aware that the doctrine that the reciprocating parts of an engine exert a force on the dead centers where they are at rest, when their motion in one direction has ceased and that in the opposite one has not yet begun, is rank heresy; as much so as was once the assertion that the earth revolves on its axis. It is, however, equally true. The demonstration of it is quite simple, and I do not doubt that at every step I shall have your entire and cordial concurrence. If we find ourselves on ground not before trodden, we shall nevertheless be sure that it is firm and solid ground.

It may be observed here, that the action which we are to investigate has no *necessary* connection with high piston-speed. Although it is what makes rapid speed practicable, and although a correct understanding of it wholly removes any theoretical objection to the employment of such speed, still it takes place at all speeds, varying only in the amount of centrifugal force developed, according to the law of central forces, namely: directly as the mass, directly as the diameter of the circle when the number of revolutions is constant, inversely as this diameter when the velocity is constant, and as the square of the speed in a given circle.

We know that the motion of a piston controlled by a crank is not uniform, but, commencing from a state of rest, it becomes at the mid stroke slightly in excess of that of the crank-pin, and at the termination of the stroke has been reduced back to nothing. In giving the piston-speed of an engine, we always name its mean speed, found by multiplying the length of the stroke, in feet, into the number of strokes made per minute; but the speed attained at the middle of each stroke is about 57 per cent greater than this, having the same relation to it that the semi-circumference bears to the diameter of a circle.

Let us take, for illustration, the case of a horizontal engine, of 16 in. diameter of cylinder, by 30 in. stroke, the reciprocating parts of which weigh 1200 lbs., and which makes 122·3 revolutions per minute. The mean piston-speed is 611·5 feet per minute, while that reached at the middle of each stroke is 960 feet per minute, or 16 feet per second.

The first question requiring to be answered is: What is the amount of accelerating force, constantly exerted through a distance of 15 inches, that is required to impart to a body of 1200 lbs. weight a velocity of 16 feet per second? We suppose the motion to be without friction, and are inquiring only for the force required to overcome the inertia of the mass. The laws of falling bodies will furnish the answer to our question.

The motion being horizontal, gravity has no effect, either to produce or to destroy it; but a force of 1200 lbs., equal to the weight of these parts, would, by being constantly exerted horizontally through a distance of 16·083 feet, give to them a velocity of 32·166 feet per second, this being the velocity imparted by gravity to a falling body.

But what velocity would this force impart, by acting through a distance of 1·25 feet? The velocity acquired by a body accelerated by a constant force, varies as the square roots of the distances through which the force acts. Thus, a falling body, to acquire a double velocity, must fall through four times the distance, and to acquire five-fold velocity, it must fall through twenty-five times the distance; and so the force equal to their weight, acting through 1·25 feet, would impart to the reciprocating parts a velocity of 8·968 feet per second.

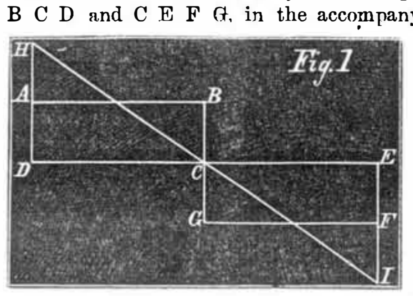
$$\frac{32{\cdot}166 \times \sqrt{1{\cdot}25}}{\sqrt{16{\cdot}083}} = 8{\cdot}968$$

But if 1200 lbs. will give a velocity of 8·968 feet per second, what force will be required to impart a velocity of 16 feet per second? The forces required to impart different velocities by acting through a given distance, must vary as the squares of the velocities imparted. Thus, to give to a body in moving through a distance of 16·083 feet, a velocity of 64·332 feet per second, or double that which gravity would impart, the accelerating force must be equal to four times its weight, and so the force required to impart to a body of 1200 lbs. weight a velocity of 16 feet per second by acting through a distance of 1·25 feet, is 3820 lbs.

$$\frac{1200 \times 16^2}{8{\cdot}968^2} = 3{\cdot}820$$

We have thus completed the first step in our demonstration. There can be no doubt that our piston, crosshead and connecting rod have attained a velocity of 16 feet per second, that this velocity has been imparted to them in moving through a distance of 15 inches, and that they must have been accelerated by a force, supposing it to have been exerted constantly, of 3820 lbs.

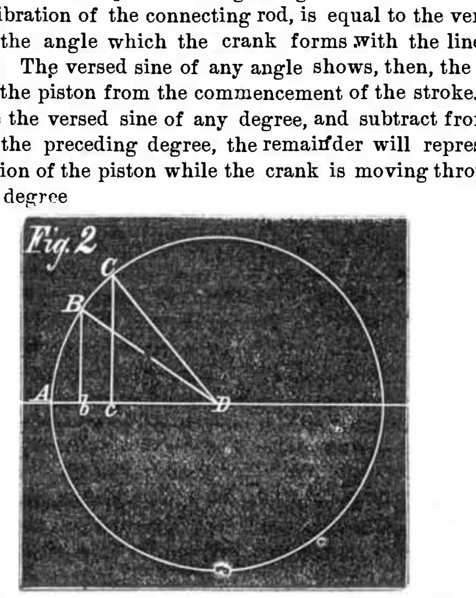
But it is obvious that the force accelerating the motion of a piston cannot be a constant force, because if it were so, then at the middle of the stroke, where acceleration ends, it must cease abruptly, and retardation must commence in the same manner, as would be illustrated by the two parallelograms, A B C D and C E F G, in the accompanying figure.



Now we know very well that, instead of this, acceleration passes at the mid-stroke into retardation, in a manner wholly insensible.

How shall this mystery be explained? There are various methods, more or less abstruse, of reaching the explanation, but there is one that is exceedingly simple, indeed so much so that it is surprising that engineers are not uniformly familiar with it. It is found by almost the mere inspection of the table of versed sines.

The motion of a piston, disregarding the effect of the angular vibration of the connecting rod, is equal to the versed sine of the angle which the crank forms with the line of centers. The versed sine of any angle shows, then, the motion of the piston from the commencement of the stroke. If we take the versed sine of any degree, and subtract from it that of the preceding degree, the remainder will represent the motion of the piston while the crank is moving through the last degree



Thus, in the above figure, while the crank is traversing the arc, A B, the piston is moving through a distance equal to A b, the versed sine of the angle, A D B, and so on.

The following table, which any one can complete, shows, in the first column, the versed sine, or total piston motion, for the first and last five degrees which the crank passes through while the piston is making a half stroke, and in the second column, obtained by subtraction as above, shows the motion for each one of these degrees.

The motion for each succeeding degree, of course, increases all the way, but in what ratio does it increase? This is the vital question. To answer it, we subtract from the motion for each degree that for the preceding one, and the difference shows the velocity imparted while the crank was moving through the last degree. In this manner we obtain the third column, showing at a glance the velocity imparted to the piston at each degree; and how wonderful is the revelation! The acceleration, at first nearly uniform, diminishes in an increasing ratio, which for the 90th degree is less than $\frac{1}{57}$ that for the first degree, and is just equal to the diminution in the acceleration for the 89th degree, showing how at the end of this degree it ceases altogether.

Degrees.	Versed sine, or total motion	Motion during each 1°.	Velocity imparted during each 1°.	Difference.
1	·0001523	·0001523	·0003046	
2	·0006092	·0004569	·0003046	0
3	·0013705	·0007613	·0003044	2
4	·0024359	·0010654	·0003041	3
5	.0038052	·0013693	·0003039	2
86	·9302435	·0173992	·0000265	
87	·9476640	·0174205	·0000213	52
88	·9651005	·0174365	·0000160	53
89	·9825476	·0174471	·0000106	54
90	1·0000000	·0174524	·0000053	53

The motion during the first two degrees seems to be uniformly accelerated; but if we should go to a sufficiently high place of decimals, we should find the acceleration absolutely greatest on the very dead center.

It will be interesting to compare this diminishing acceleration with the uniform acceleration of the motion of a falling body. The following table represents the latter; decimals are omitted for convenience, but this does not at all affect the table for the purpose of this comparison. The second and third columns are derived from the first by subtraction, in the same manner as above.

Seconds.	Total distance fallen through.	Distance fallen in each second.	Velocity in feet per second imparted during each second.
	ft.	ft.	
1	16	16	32
2	64	48	32
3	144	80	32
4	256	112	32
5	400	144	32
6	576	176	32

If now, at each degree, we draw an ordinate, perpendicular to the line of centers, and of a length proportionate to the acceleration at that degree, we shall find that a straight line connects all their extremities, showing the acceleration to be represented by the right-angled triangle, D C H, Fig. 1. This any one can verify.

It is thus revealed to us, that precisely on the dead center the acceleration of the piston's motion is double its mean acceleration, and the force required to produce it is twice that which would be constantly required; or, in the case we are considering, is 7640 lbs., equal to a pressure of 38 lbs. on each square inch of piston area.

The fact is so important, that it may be well to exhibit it also in another manner. We have seen that the motion of the piston is, for the first two degrees, accelerated in a manner which may be regarded as uniform. The distance moved through by a body uniformly accelerated, increases as the square of the time, as shown in the last table.

If, then, we take the coefficient of the motion for the first degree, ·0001523, and multiply it by the square of the number of degrees traversed by the crank in one second, we shall have the distance which the reciprocating parts would be moved in one second, at their original rate of acceleration, supposing it to be continued uniformly during that time, if the length of the crank equaled 1. This distance is 82·05254 feet, for the crank moves in one second through 734 degrees, and $734^2 \times {\cdot}0001523 = 82{\cdot}05254$. The length of the crank is, however, 1·25 feet, so that the distance moved through would be 102·5 feet. This distance, divided by 16·083, gives the quotient 6·37, which is the accelerating force in terms of the weight of the parts. But $1200 \times 6{\cdot}37 = 7644$, the same result as before.

The second point in our demonstration is now established that on the dead center, where motion begins to be imparted to the piston, it is imparted in double the average ratio, and the force required for this purpose is just twice as great as a uniform accelerating force would have to be, to give to it the velocity that it has at the mid-stroke.

The retardation of the motion of the piston by the crank, bringing it to rest at the end of the stroke, is the reverse of the acceleration, commencing insensibly at the middle, and culminating at the termination of the stroke, and is represented by the triangle, E, C, I, Fig. 1. This, to one who has clearly apprehended the acceleration, must be sufficiently obvious.

We are arrived now at our final proposition, that the resistance offered by the reciprocating parts to this alternate acceleration and retardation is, at its culminating point, the dead center, precisely the centrifugal force that the same weight would exert continually, if it were revolving with the crank pin.

Let us examine this action in the light that has now been thrown upon it. We will suppose the steam to be suddenly shut off, so that the acceleration, as well as the retardation, is effected through the crank. We note, first, this distinction, that while at the mid-stroke acceleration passes when diminished to nothing into retardation commencing at nothing; at the centers, on the contrary, retardation passes at its maximum into acceleration at *its* maximum. A closer examination shows, however, that while, in the first case, the direction of the force changes, in the latter it does not change. This direction must be reversed twice in each revolution, and this reversal takes place at the middle of each stroke, and not on the center. The crank begins, at each mid-stroke