The Flather Hydraulic Dynamometer.

By
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The Flather Hydraulic Dynamometer is a form of transmitting dynamometer which was first constructed by Prof Flather, of Pardue University. The following is a description of the one owned by the Mechanical Department of the Kansas State Agricultural College.

A hollow shaft carries three eighteen inch pulleys. One of these is fixed rigidly to the shaft, and one is entirely loose so that it can turn on the shaft. These two act as ordinary fast-and-loose pulleys, by means of which power can be transmitted by the dynamometer or not, as required. The third pulley is fixed to the shaft by a device for measuring the force required to turn the pulley, and hence, the force required to run any machine to which this pully may be belted. Fixed to the shaft at the side of this pulley, are two cups opposite each other. Each of these cups is accurately turned inside to receive a plunger, and they are pivoted on trunnions so that they can have a small motion of rotation in a plane perpendicular to the axis of the shaft. They are so placed that the open end of each is in the direction of rotation of the shaft. There is a hole in the bottom of each cup, which is connected by a flexible tube, to the inside of the hollow shaft. On each of two opposite arms of the pulley, is a stub, to which the plungers that fit into the cups on the shaft, are attached. Now when power is given to the shaft, if no work is being given out by the dynamometer, the plungers will keep the same position with relation to the cups; but if the receiving pulley is belted to some source of power, and the transmitting pulley is belted to some machine, the resistance to turning of the transmitting pulley, will tend to force the plungers into the cups, and thus to compress the air or other fluid within the cups. But these cups are connected to the inside of the shaft, so that the pressure is conveyed to it as well. Now suppose one end of this hollow shaft to be closed firmly, and the other end to contain a tightly fitting piston. It is clear that the force applied at the surfaces of the plungers in the cups, will be transmitted, through the fluid to the piston in the end of the shaft; and by the laws of hydraulics, the total amount of force acting on the plungers, and this piston in the shaft, will be proportional to their respective areas. The motion of the piston in the shaft is resisted by a spring, and is communicated to a lever arm carrying a pencil. By means of a worm on the shaft and suitable gear wheels, a table carrying a paper card is made to slide along under the pencil, whenever the shaft turns. The speed at which this paper is drawn along is proportional to, though very much less than, the speed of the belt over the pulley.

When the shaft is made to rotate, and the transmitting pulley is belted to some machine, this transmitting pulley will evidently resist the rotation of the shaft. This resistance is conveyed, by means of the plungers, to the fluid, usually oil, in the cups; and thence to the piston in the end of the shaft; and the motion of this piston is recorded by the pencil on the card. Thus we have a curve drawn, the abscissas of which are some function of the distance travelled by the belt over the pulley, and the ordinates of which, measured from the base line found by running the dynamometer when it is not transmitting any power, are some function of the force required to run the machine which is being tested. The area of the curve, then, is some function of the horsepower absorbed by the machine.

To calculate the horsepower used by a machine from the diagram obtained, requires some investigation. It is necessary to find out whether or not the distance through which the spring in the shaft is compressed, is exactly proportional to the force exerted upon it, and also the relation between the force applied to the spring and the amount of movement of the pencil. In order to test this, a steam engine indicator was connected with the inside of the shaft, at the end opposite the pencil. Then the whole device, shaft, cups, and indicator, was filled with oil, and known weights of $\frac{1}{2}$ pound, 1 pound, $1\frac{1}{2}$ pound, etc, were applied to the piston of the indicator.

The area of the piston of the indicator was equal to that of the piston at the other end of the shaft, so that a force of one pound, applied to the one, would be transmitted through the oil, and exert a force of one pound on the other. These different weights were applied, and the position of the pencil was marked each time. The experiment was repeated several times, the distances between the different positions of the pencil were carefully measured, and the results were plotted, using the weights applied as abscissas, and the distances through which the pencil traveled as ordinates. The data gave in each case very nearly a straight line, showing that the distance through which the pencil moved was proportional to the force exerted on the piston in the shaft. It was also found from the data, that a movement of the pencil, of one tenth of an inch, represented a difference in pressure on the piston of one pound per square inch.

The work transmitted by the dynamometer in one minute is the total force with which the two plungers press upon the oil in the cups, multiplied by the distance through which the pivots of these cups move in one minute. Or, if W is the work transmitted, F the total force on the two plungers, and S the space passed through by the pivots in one minute, then

$$W = FS \qquad (1)$$

But $F = p \times 2a$ if p is pressure per square inch on the plungers, and a is the area of each plunger. a was found to be ten square inches, and p can be expressed in terms of y, the distance through which the pencil moved. We have already seen that a movement of the pencil, of one tenth of an inch represented an increase in p of one pound per square inch. Hence $p = 10y$. Then $F = 2 \times 10 \times 10y = 200y$.

S, the space passed through by the pivots per minute, is evidently the circumference of the pivot circle, times the number of revolutions per minute made by the shaft. The circumference of the pivot circle was found to be $3.1416 \times .647$, or 2.032877 feet. The number of revolutions per minute was

found by counting to be 369.1444.
S then is equal to 2.032877 x 369.1444,
or 750.425 feet. Substituting these values
of F and S in formula (1)

$W = 750.425 \times 200y = 150085y$ foot-pounds per minute. This divided by 33000, gives

$W = 4.548y$ horsepower (2)

The whole process of finding the horsepower required to run a machine, is as follows.
Fill the shaft and cups full of oil, fasten a card to the table beneath the pencil, and adjust the pencil so that it presses very lightly upon this paper. The more lightly the pencil presses, the better; for if it presses heavily, the friction between it and the paper, will affect the result quite materially. Next, belt the receiving pulley, which may be either the one fastened rigidly to the shaft, or the one fastened to it by means of the cups and plungers, to some source of power; and belt the transmitting pulley to ~~the~~ machine to be tested. Shift the latter belt onto

the loose pulley on the shaft, and run the dynamometer alone to get a base line. The table will be drawn along and the pencil will make a line which is, in general, a straight line. Then shift the belt going to the machine to be tested, back onto the transmitting pulley, and repeat the operation. The line drawn by the pencil this time will take a different position on the paper, and will be, in general, straight or not, according as the load on the machine is constant or not. The average distance between the two lines, multiplied by 4.548 gives the number of horsepower used by the machine. Diagram 1 on the next page was obtained in testing a small dynamo, supplying ten, sixteen-candle-power, incandescence lamps. The line 0, 0, was drawn when the dynamometer was run alone; and the line y, y, when the dynamo was run with lights connected. The average distance between the lines is .204 inch, and this multiplied by 4.548, gives .927

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Name No. 1.

Speed Spring Stroke

Pounds Discharge Total Lift Suction

Area of Diagram Length

Av. Height Av. P. Work per Stroke

Name No. 2.

Speed Spring Stroke

Pounds Discharge Total Lift Suction

Area of Diagram Length

Av. Height Av. P. Work per Stroke

as the horsepower used by the dynamo.

In diagram 2, the base line 0,0, was obtained as before, when the dynamometer was not transmitting any power; and of the two lines y,y, the one nearer the base line was obtained when the dynamo was run without lights connected, and the other when the dynamo was run with lights connected. This diagram gives as the power required to run the dynamo empty, .6 horsepower, and as the power required to run the dynamo loaded with ten light, .955 horsepower. This last number does not quite tally with the result obtained from diagram 1, probably owing to the fact that in the first case, the average of several diagrams was used, while in the last, only the one diagram was measured.

There are some sources of error in testing a machine, which cannot be eliminated. The friction of the plungers in the cups, of the piston in the shaft, and of the pencil on the paper, all interfere with freedom of movement of the pencil, and hence with the correctness of the curve drawn.

The number of revolutions per minute of the dynamometer shaft may vary, from several causes. The speed of the source of power may vary for different experiments. The speed may vary with the load on the machine being tested. As a matter of experience, this is often the case, due to slipping of belts, etc. In obtaining diagram 2, the difference in speed when the lights were turned on, and when they were turned off, was quite apparent. The number of foot-pounds of work transmitted per minute, varies with the number of revolutions per minute, of the dynamometer shaft, and so, if this number is different when the diagram is taken, from what it was when the revolutions were counted, the result is obviously incorrect.

Again, in measuring the average distance between the lines in the diagram, extreme accuracy is very difficult to obtain, on account of the irregularity of the lines. From the formula $W = 150085\,y$ foot-pounds, it is plain that a small error in measuring y, makes quite a difference in the result obtained. A difference of .001 inch in y, means a difference in the answer, of 150 foot-pounds per minute, or .004548 horsepower.