(Paper No. 2436.)

“A Hydraulic Pumping-Engine.”

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THE object of this Paper is to describe a Hydraulic Pumping-Engine of a new type designed by the Author, and made in England for the Isabella Furnace, Chester County, Pennsylvania, where it is now at work. It is the second engine constructed upon this principle; the first having been erected at St. Mary Cray, Kent, chiefly for experimental purposes. Accurate tests of efficiency have been made in both cases, and the results are quoted below.

As in the Hydraulic Ram, the pumping-power is obtained by the arrest of a column of water which has been previously set in motion by the force of gravitation, and the duty obtained demonstrates that this principle may be safely and advantageously employed much more largely than hitherto. The blow or concussion generally supposed to be a necessary concomitant of machines of this type, is entirely avoided, and the action made equal in smoothness to that of the best class of reciprocating-pumps, not only without interfering with the efficiency but with the result of increasing it. This being the case, engines of such a type have the obvious advantage, as compared with a combination of turbines and pumps, that the energy available is utilized directly, without being first transformed into rotary motion, and from that by a second conversion into the form in which it is required, and the undesirable combination of a fast-moving engine such as a turbine, driving a slow-moving machine such as a reciprocating pump, is avoided.

An efficiency considerably higher than any hitherto attained in machinery of this kind was therefore to be expected, and, as will be seen by the tests, has been already realized.

Fig. 1 shows the construction of the engine at the Isabella Furnace:

C is a pipe 1 foot in diameter from the head race to the engine.

D is the main valve (more fully described below) actuated by the rod E and the cam F, and alternately opening and closing the annular opening G.

Fig. 1.

HYDRAULIC PUMPING-ENGINE.

H is a chamber above the main valve, the use of which is explained below. It has an equilibrium valve at J.

K K are valves opening from the chamber H into the valve-chamber L, which communicates with an air-vessel by the pipe M.

A small motor of ordinary construction, not shown in the *Fig.*, turns the shaft O and cam F, and thus opens and closes the main valve D.

The action of the engine is as follows :—

The shaft O is turned by the motor at a speed of about 25 revolutions per minute, and, by means of the cam F, actuates the main valve D, and alternately opens and closes the orifice G at regular intervals. Immediately the orifice G is opened, the water flows in the pipe C, escaping freely into the tail race, until by the continued revolution of the shaft O, the cam again closes G. During the closing, however, which takes place quite slowly, some water rises in the chamber H, driving out the air which escapes from the chamber through the valve J. This action is one principal object of the chamber H, and helps more than any other feature of the engine to make it possible to utilize the principle of the hydraulic ram without violence on the one hand or loss of efficiency on the other. It is obviously objectionable to have to close the valve very quickly; while the slower it is done, but for the function performed by the chamber H and valve J, the greater is the loss which results from checking the flow of the water. But as, by this construction, a second way is open to it during the shutting of the main valve, the current is not impeded and the valve may be closed as slowly as is convenient, without any loss from this cause.

The annular sliding-valve D is peculiar in that its closing is completed by a slight movement of the seat P, which consists of a rubber-ring in the form of a curtain. The valve is moved up to, but not quite touching it. Immediately there is any internal pressure the edge of the rubber curtain is forced against the valve, and so completes its closing. This arrangement has, in addition to the advantage of durability, that of not being injured by sticks or floating rubbish if such should be brought down by the water. Almost immediately after the closing of the main valve, the water, still rising in the chamber, reaches the lower edge *a* of the tube *b*, up which it flows, touches the float *c* attached to the air-valve J and closes it. The momentum of the column of water then compresses the small quantity of air contained in the chamber H above the lower edge of the tube *b*, opens the valves K K, and forces into

the valve chamber L (and thence into the air-vessel), first the air and then some of the water following it. Having thus expended its energy the water comes to rest. The valves K K then close. After this has occurred the continued revolution of the shaft O and its cam F reopens the main valve D. The flow in the pipe C recommences, and at the same time the water in the chamber H also escapes into the tail-race through the same opening, atmospheric air entering through the air-valve J, which falls open as soon as the high pressure ceases. This completes the cycle of operations, the delivery of water at high pressure from the air-vessel being continuous.

In order to ascertain whether there is any violence of action in

Fig. 2.

Fig. 3.

CRAY ENGINE, PUMPING AT 30 LBS.
PER SQUARE INCH.

CRAY ENGINE, PUMPING AT 30 LBS. PER
SQUARE INCH.

Scale 30 lbs. = 1 inch.

the pipes and the chamber, a tube was fitted into the chamber H, and a steam-engine indicator attached, the barrel of the indicator being driven from the crank-shaft.

A great many diagrams were taken, some of which accompany this Paper, *Figs. 2, 3, 4 and 5*; the point *a* corresponds with the time of shutting of the 12-inch valve. From *a* to *β* the pressure rises a little during the escape of air through the passage, and further increases from *β* to *γ*, during the compression of the air left in the chamber which thus forms a cushion. It will be seen that the pressure usually rises to about 2 lbs. more than the resistance in the rising main. This is just about the difference due to the velocity at which the water passes the delivery valves. The marks above *γ* are obviously instrumental vibrations due to momentum

of the indicator. As the velocity diminishes this pressure becomes less, showing a gradual closing of the delivery valves. After this has happened it almost immediately falls to zero, and in some

Fig. 4.

CRAY ENGINE, PUMPING AT 35 LBS. PER SQUARE INCH.

Fig. 5.

BARNESTON ENGINE, PUMPING TO RESERVOIR.

Scale 30 lbs. = 1 inch.

cases to a little below. In the latter case there was apparently a slight recoil; but it was obviously very slight, as the air-valve would not fall open when completely balanced. These diagrams prove the perfect smoothness of working, and entire absence of the

blow which is frequently supposed to be a necessary accompaniment of machines on this principle.

The motor referred to is actuated by the small quantity of air which, as has been already mentioned, is compressed at each stroke and enters the air-vessel with the water. The depth of the tube *b* dipping into the ante-chamber is easily regulated by the screw *R*, so that the quantity of air compressed may be made equal to the requirements of the motor.

When the engine has been once set to work, it can of course be stopped and started without any difficulty, but on first starting it is desirable to charge the air-vessel to a pressure equal to the pumping head. This is easily done in a few revolutions of the engine, the dipping tube *b* being first adjusted to its lowest position, which is about 6 inches below that shown in the drawing. The effect of so doing is to confine a considerable quantity of air in the ante-chamber instead of the small amount required by the motor so that the pressure rises with each stroke, and rapidly becomes sufficient for working.

The ordinary work of this engine is pumping water to a reservoir 610 feet distant, and 92·7 feet above the engine. It delivers a perfectly steady stream into the reservoir without any kind of concussion or water-hammer effect, the only sound being that of the closing of the valves *K*. The water was carefully gauged over a weir constructed for the purpose by Mr. W. M. Potts of Pennsylvania, for the proprietor of the Isabella Furnace, and both he and the Author made many measurements, during several days, of the quantities used and delivered. Mr. Potts' report of the result is given in Table I. The quantity delivered according to the measurements made by the Author, was slightly in excess of that measured by Mr. Potts, being 130 American gallons, giving a net efficiency of 73·5 per cent.

Particulars of tests made on the engine at St. Mary Cray are given in Table II. The last column is the result of a recent test, and includes, in the quantity of air compressed, that used in the motor. As the proportion of power consumed in this way is of course greater for a small engine than for a large one, these figures are useful as showing what may be expected in air-compression on a larger scale. Deducting the air used in the motor the net efficiency was 76 per cent.

The efficiency obtained was not quite so high as in the one described (it being of an earlier design), but the record is of some interest, as the measurements were made when it was compressing air as well as pumping water. In this case the efficiency is con-

siderably higher than when simply pumping water, and it would probably be still greater if the engine were only compressing air. The reason of this is to be sought in the exceptionally favourable circumstances under which the action takes place. The whole interior surface of the compression-chamber is cooled at every stroke by a mass of cold water acting as a piston, the movement of which is comparatively slow. The compression is consequently very nearly isothermal; repeated observations with thermometers placed in various positions failed to detect any rise of temperature.

As the engine was intended for the purpose of pumping water, and only incidentally as an air-compressor to the extent necessary for charging the air-vessel, the ante-chamber was not made large enough to contain sufficient air to absorb the whole power of the water column. This is why, in the record of experiments on efficiency in air-compressing, pumping water still forms part of the work done. It may be mentioned, however, that the engine constructed for the Isabella Furnace was erected for a few weeks for experimental purposes under a fall of only 5 or 6 feet, and with this small head the ante-chamber held sufficient air, when the dipping tube was lowered, to absorb the power of the water column in compressing it. The engine was allowed to run for a considerable time in this way, working solely as an air-compressor, and it was found that the quantity of air confined could be regulated with sufficient exactitude to prevent any waste, whether by excess or by deficiency, but the circumstances did not admit of the efficiency being measured.

Another result was demonstrated in the engine at St. Mary Cray, which there was no opportunity to test at Barneston. The head against which it was pumping was frequently varied by opening or closing a sluice-valve in the rising main. No alteration of the speed of the engine or any gearing down or up was necessitated by such a fluctuation of head, the quantity delivered instantly increasing or diminishing accordingly. On one occasion water had to be used which carried in suspension large quantities of earth, gravel, and even stones, besides floating chips, sticks and rubbish of various kinds to such an extent that a steam-pump which was in use at the same place could not work at all and was choked up and stopped many times a day. It did not, however, obstruct the action of the hydraulic engine on any single occasion.

The Paper is accompanied by three drawings and seven pressure diagrams, from which the *Figs.* selected for its illustration have been prepared.

APPENDIXES.

APPENDIX I.—MEASUREMENT OF THE EFFICIENCY OF THE HYDRAULIC PUMPING-ENGINE AT BARNESTON.

By Mr. WILLIAM M. POTTS.

The head of water—that is, the vertical distance from surface of water in dams to centre of waste-water discharge of engine is	17·25 feet.
The vertical height that water is lifted is	92·70 „
The discharge-pipe from engine to reservoir is 4 inches inside diameter, 610 feet long, and has six curves or bends and one straight-way valve in it. The resistance of this pipe is calculated as 7·91 feet, making the total head against which engine works 100·61 feet = 43·67 lbs. per square inch. The indicator diagrams show a pressure of 44 lbs. per square inch, when the delivery valves are closing.	100·61 „
Water delivered per minute into the reservoir, the average of a number of tests	125 American gallons.
Waste water from the engine per minute, weir measurement	901·8 „ „
Total quantity of water used by the engine per minute	1026·8 „ „
Efficiency of the engine = $\frac{125 \times 100 \cdot 61}{1026 \cdot 8 \times 17 \cdot 25} = \frac{12576 \cdot 25}{17712 \cdot 3} = 71$ per cent.	

APPENDIX II.—MEASUREMENTS OF THE EFFICIENCY OF THE HYDRAULIC PUMPING-ENGINE AT ST. MARY CRAY, KENT.

Head of water, in feet	7·79	7·76	7·810	7·850	7·440
Resistance in the rising main measured by the pressure-gauge . . .	79·50	78·40	86·500	68·100	72·400
Quantity of water delivered per minute, in imperial gallons . . .	49·80	52·00	17·600	39·100	28·000
Quantity of flow to tail-race per minute, in imperial gallons . . .	725·00	725·00	571·600	611·500	642·000
Total quantity of water used per minute, in imperial gallons . . .	774·80	777·00	589·200	650·600	670·000
Quantity of air compressed in cubic feet per minute	..	..	7·316	5·128	9·126 ¹
Efficiency of the engine per cent. .	65·80	67·70	75·610	75·480	87·000 ¹

¹ Including air used in motor.