# REVIEW

OF THE

# McALPINE PUMPING MACHINE,

RECENTLY CONSTRUCTED FOR THE

# NEW BEDFORD WATER-WORKS.

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WITH AN INTRODUCTION BY

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This paper was written by Mr. R. E. Briggs, a graduate of the Rensselaer Polytechnic Institute of Troy, New York, but having been read before the class of graduates of 1868, could not, by the rules of this Society, be received as an original paper, or be read before it. I was, however, requested to read it to the members informally, after the adjournment of the American Society of Civil Engineers.

In doing so, I stated in substance as follows:

I have carefully examined this paper, and fully agree with the author in the statements of the principles which should govern in the construction of Pumping Engines, in the facts stated, and in the arguments advanced in favor of the principles enunciated.

So many Engines for water-works are now called for, that I believe that the publication of this paper will be of service to the profession, even to those who may not entirely agree with the views of the author or myself, as to the best forms of Pumping Engines.

I take the liberty of recommending it to the perusal of those engaged in the planning and construction of works of a similar character.

William J. McAlpine,

*Civil Engineer, member of the London Society of Engineers, and of the American Society of Engineers, etc., etc., etc.*

# REVIEW

OF THE

# McALPINE PUMPING MACHINE.

The duty to be performed by a pumping machine is peculiar, and differs materially from nearly all of the other applications of steam power.

The resistance to be overcome is nearly constant, and the power, at all times, must be at least equal to this load.

At every change in the direction of the movement of the piston of a water pump (that is, at the end of each stroke), the momentum of the water in and near the pump which has been absorbed, is destroyed, and at the commencement of the succeeding stroke, the power is first exerted to develope the inertia of the water and again set the column in motion.

These changes take place in all reciprocating pumps, and a primary object in the arrangement of a pumping machine is to reduce the resistance from these changing motions to a minimum.

Steam working expansively, meets the requirements of a reciprocating pump exactly.

When first admitted into the cylinder, it has a pressure much greater than that due to the weight of the column of water against which it is to act. The inertia of the water is therefore rapidly overcome, and so long as this higher degree of pressure is continued, so long does the velocity of the water continue to increase, and thus absorbs the excess of the power in its own momentum. The supply of steam being shut off from the cylinder, that which it contains, continues to exert its pressure against the piston, but expanding as the steam space increases, its pressure is gradually diminished, until it falls below that due to the normal weight of the water load on the pump, at the beginning of the stroke.

The excess of power beyond the resistance of this normal weight, which has been developed at the beginning of the stroke and treasured up in the momentum of the water, fly-wheel, and moving parts of the machine, is yielded up during the remainder of the stroke, and aids the waning power of the steam to force up the column of water.

The speed of the piston is gradually diminished, and if the cut-off is properly adjusted, the whole power at the end of the stroke, will be just sufficient to turn the centres and open the valves very slowly and with no excess of power.

The operation thus described, is the perfection of movement in a reciprocating pumping machine. The slowness of motion at each end of the stroke, opens and closes the valves without noise, injury, and with the least loss of water; the water in the pump chamber has lost its motion, and the piston begins the return stroke through water almost at rest, and with the minimum degree of friction, while the moving parts of the machinery are gradually brought to a state of rest, without concussion or injury.

The resistances to be overcome by the power of a pumping engine are:

*First.* The inertia and the friction of the several parts of the machine.

*Second.* The elevation of the water.

*Third.* The inertia and the friction of the water through the pumps, valves, connecting pipes, and force main.

When steam is applied to this purpose, the increased power which may be derived from its expansion, should be availed of to the greatest practicable extent; but where reciprocating pumps are used the excess of power beyond the resistances, developed by the initial pressure of the steam, must be exhausted at the termination of each stroke to produce the best results.

The absorbents of this surplus power are:

*First, and chiefly.* The momentum of the ascending column of water.

*Second.* The momentum of the moving parts of the machinery, except that of the fly-wheel.

*Third.* The momentum of the fly-wheel.

*And lastly.* The compression of the air in the air-vessel, and also the surplus power expanded in the extra elevation of the water in the standing column.

With reciprocating pumps it should be arranged, so that the surplus power of the steam engine thus absorbed, is again given out before the commencement of the next stroke, and all of it contained in the momenta, except a very small portion of that in the fly-wheel (by a proper adjustment), may be applied to aid in overcoming the resistances of the ascending column of water.

The extent to which the expansion of the steam may be carried will be determined by the amount of the absorption of the excess of the initial power in these different momenta and its release during each stroke.

It will probably be found that an expansion of three times in the steam cylinder, will produce the maximum degree of useful effect; but the most useful rate of expansion in any particular steam engine, can only be definitely determined by direct trial.

Direct-acting pumps are used to avoid the loss of power in the friction of the machinery necessary to convey it to them; but the practical difficulty of always maintaining the steam and water pistons in perfect alignment, probably causes as much loss of power as would be incurred in its transmission to an indirect-acting pump; and as it is impossible to move water at the same velocity as steam, a serious waste of power, direct-acting pumps are objectionable.

The ordinary beam engine affords the means of giving the proper velocity both to the steam and water pistons, with only two extra journals, both of which have a slow movement of less than five degrees, the friction of which is therefore inconsiderable.

The vertical beam engine has also two advantages over one working horizontally, viz., in avoiding the friction due to the wright of the pistons resting on the lower part of the cylinders, and in giving an opportunity to absorb more of the surplus initial power, in the momentum of the vertically moving parts of the machine.

It also allows the moving parts, on the opposite sides of the beam centre, to be accurately balanced. It permits of extreme simplicity in its construction, all the parts of which are nearly of the same form as those of the most numerous class of steam engines in use, and of giving convenient access to all of its parts, with none of them liable to undue wear or strain, and with the least loss of power by friction, and it permits, almost without extra cost of construction, a large increased velocity without danger, and also a very low velocity without much waste of power.

Reciprocating pumps of three classes are used, viz.: single, double-acting, and plunger. In the first the water is lifted by a valved piston; in the second by a solid piston, which alternately lifts and forces the water, and in the third by a solid plunger, which displaces the water in the pump-chamber, and forces it out through the upper valve.

All Hydraulicians agree that it requires an increased amount of power to force water through a pipe, whenever the area of its volume or its direction is changed, and that even a sudden enlargement causes an obstruction, in some cases as great as a contraction.

The importance of avoiding all abrupt changes of volume, or direction in water pipes, is fully recognized in the practice of all skilful engineers, in the arrangement of their main and distribution pipes. In the former, all changes of direction are made by curves of large radius; and in the latter, the entrances to the crossing steam pipes are always made with as large a radius as the case will admit.

On this subject, Daubicisson says: § 196, "Every moving body which, after following one direction, suddenly changes it, loses a part of its velocity." * * * * "If however, a fluid follows a curved line, this loss, although real, will usually be very small." * * * * * "Rennie's experiments show that a single abrupt right angle reduces the discharge more than fifteen semicircular curves of a radius six times the diameter of the pipe." * * * * "The effect of enlargements in a conduit pipe, are quite as prejudicial as that of contractions taken above a certain limit."

Other writers assert that the obstruction caused by an abrupt bend, is six times as great as when made by a gentle curve, giving the same amount of deflection.

The Civil Engineer rarely determines more than the general style of the pumps, and usually leaves to the practical mechanic the arrangement of the direction and form of the water passages. As these are analogous to his steam passages, he is naturally led to arrange them alike, forgetting that in one case he is dealing with an *elastic vapor*, which loses but a small portion of its force in these diversions, while in the latter he is dealing with an *incompressible fluid*, where the loss is comparatively very much greater. Hence we find him forcing water through his pumps with a dozen changes of volume and direction, which the engineer would consider totally inadmissible, after the water leaves the delivery pipes of the pumps.

In a single-acting pump the direction of the water is not changed, and in a plunger pump there is but one change of direction. In a double-acting pump there must necessarily be changes of direction, equal to five right angles, which at every revolution, twice destroys all of the acquired momentum of the water.

The single-acting pump has one more valve passage than the others, and with butterfly valves its volume is divided into two semi-cylindrical columns at each; and has two extra slightly abrupt changes in the volume of the water in passing through the bucket valve in the piston, to offset against the five right angles of the double acting pump, or the one right angle in the plunger pump. The single-acting pump will therefore deliver the same quantity of water, with expenditure of less power, than the plunger pump, and very much less than with the double-acting pump.

It has, however, been stated that the single-acting pump delivers the water, with no change of direction. In practice, however, it is necessary to extend the vertical delivery pipe to a horizontal direction, which gives the same number of changes of direction as in the plunger pump; but this change is made in the former on a gentle curve, and in the latter by an abrupt angle.

The English mechanicians almost universally use what are termed balanced double-beat valves. These valves divide the ascending column of water into two parts, one cylindrical and the other annular, and both of them are forced through three abrupt right angles before they are again united in the solid column above the valve.

The American mechanicians have, to a considerable extent, followed the English practice, and extended it by making three beat, and in one case four beat valves for pumps, and thus still further dividing the column of water.

Both mechanicians, however, use butterfly valves in their air-pumps. This form of valve divides the column of water into two semi-cylinders, and places an obstruction in the middle of the pipe, which with a small but abrupt turn at the seating causes some loss of power; about one-third of the weight of the valve has to be raised at each stroke; but the whole loss of power in these valves is very much less than in those of the double-beat form.

It is evident that an elastic, almost imponderous vapor like steam, can be moved with a greater velocity than an incompressible, ponderous fluid like water, and therefore in all direct-acting pumps the movement of the steam piston will be too slow, or that of the water piston too fast, to produce the most useful effect in the combined machine.

An approximation to the proper velocity to be given to the water piston can be arrived at by an examination of the movement of the plunger of a Cornish pump. That kind of pumping machine consists essentially of two separate engines, each of which perform their functions almost independent of each other. The power of the steam is first applied to elevate a heavy weight, which is carefully graduated, so as to be slightly in excess of the resistances which are to be overcome in the elevation of the water. The movement of the first part of the descent of the plunger of the water pump is the most easy, natural, and appropriate motion to overcome these resistances that can be devised. At the termination of each stroke (both of the pump and steam pistons) there is a sensible pause, which allows the valves to quietly close. The plunger begins its descent with a scarcely perceptible motion, until it has developed the inertia of the water, and then gradually increasing the velocity of its descent as the resistances diminish and its own momentum increases, until it has obtained a regimen of velocity, which can be exactly regulated by the weights placed on the plunger.

The last portion of the stroke would be performed with too great a velocity if it was not checked by cushioning in the top of the steam cylinder. The average velocity of the plunger of the Cornish pumps when properly loaded, is about one hundred and twenty-five feet per minute. This is also about the velocity of other well-arranged pumps of this size, both in this country and in Europe.

The natural movement above described is almost exactly imitated by the action of the steam in the New Bedford machine, but the movement during the last part of its stroke is more perfect.

The standing column and air-vessel each perform the same function. The former permits the impulse of the steam at the beginning of the stroke to elevate a very short column of water to the extra height, due to the increased velocity of the pistons at this part of the stroke, instead of acting directly upon the longer column of the pump main. In the former case the inertia to be developed is only six tons, and in the latter it is nearly one hundred.

The compression of the air in the air-vessel accomplishes the same result.

It has sometimes been erroneously supposed that the excess of power thus communicated to these two adjuncts again usefully acts upon the ascending column of water in the pump main. It does act against the water in the main by this increased head in the standing column and by the increased pressure in the air-vessel, but each of these forces also reacts directly back upon the pumps with the same pressure, and they therefore exactly neutralize each other and produce no useful effect.

We will now proceed to the consideration of the McAlpine Pumping Machine, designed for the New Bedford Waterworks.

## GENERAL DESCRIPTION.

The water is brought a distance of six miles to the Receiving Reservoir near the city, by a conduit of an egg-shaped oval form, the horizontal interior diameter being three feet and the vertical four feet. It is built the width of a single brick (five inches wide), made to patterns corresponding with the arcs of the curves in the different parts of the oval.

From the Receiving Reservoir the water has to be forced about half a mile into the Distributing Reservoir, which is one hundred and fifty-four feet above tide-water, making the vertical lift one hundred and thirty feet.

The Pumping Machine to accomplish this was designed by the Hon. Wm. J. McAlpine, and the contract for it was given to George W. Quintard, of the Morgan Iron Works, New York, on his proposal to build the maahinery and deliver it set up and at work, including gauges, clocks, tools, etc., for thirty-two thousand two hundred dollars, but owing to his having sold his establishment, the machine will be built by Rogers and Coryell, at the Quintard Iron Works, New York.

The McAlpine Pumping Machine has been arranged in accordance with the principles which have been enunciated in the preceding part of this paper.

It consists of a vertical, beam, condensing, expansive steam engine, and two vertical, single-acting pumps, one of which is placed on each side of the beam centre.

Its general dimensions are as follows: Steam cylinder thirty-eight inches diameter and eight feet length of stroke; working beam twenty-seven feet long and of seven tons weight; fly wheel sixteen feet diameter and twelve tons weight; two single-acting pumps, each twenty eight inches diameter and four feet eight inches stroke; air-pump twenty-seven inches diameter and thirty-four inches stroke; two cylindrical tubular boilers six feet diameter and eighteen feet in length.

The working beam centre is supported on a column of cast-iron, four feet in diameter and twenty-two feet high, bracketed and bolted to a cast-iron foundation plate thirty-six feet long and five feet wide, and to the bed-plate, eighteen feet long and five feet wide, and all resting on and bolted to massive walls of granite. This column forms both the condenser and air-vessel.

The pump centres are placed on the beam, at such distances as will give a velocity to the water piston of 116⅔ feet per minute, or rather fifty-eight and one-third per cent. of the velocity of the steam piston.

The practical mechanics have determined that the most judicious velocity of steam piston for a steam engine of this size, is about two hundred feet per minute, and it has already been stated that the maximum rate of expansion should not exceed three times.

This pumping machine has been arranged to elevate two millions of gallons of water in ten hours, into the reservoir one hundred and thirty feet feet above the pump well, through a pipe of sixteen inches diameter and twenty-two hundred feet long, the friction of which will increase the constructive head to about one hundred and fifty-five feet.

For the first five years the demand for water will be but one-half of the above quantity, and at some future time it is believed that this demand will be quadrupled.

The steam engine has been arranged with special reference to these conditions, so as to consume the fuel to the best advantage under each of these conditions. Accordingly, the steam is intended to be used at a temperature which will give a pressure, at its entrance into the steam cylinder, of twenty pounds per square inch.

It will be observed by the plans of this pumping machine, that the water has but two changes of direction in passing from the pump well through the suction pipe, valves, chamber, and delivery pipe, to the pump main. The first of these changes of direction is where the water leaves the vertical line of the pumps, and takes the horizontal line of the delivery pipe, and this is made by a curve of twenty-six inches radius, and ninety degrees of deflection. The second change is where the delivery-pipe is curved horizontally into the pump main, which is so placed as to accommodate a second engine which may hereafter be required. This curve made on twenty-four feet radius, is extended until it gives forty-five degrees of deflection.

It will also be observed that the cylindrical form of the water is not changed. It is, however, split in two equal parts in passing through each of the three valves. Below each of them it is contracted by a gradual curved taper, and above the upper valve also by a gradual taper into the delivery pipe. An unavoidable sudden but small enlargement takes place when the volume of water passes the valve seat. When opened, the valves offer an obstruction in the centre of the column, which is more serious than all of the other obstructions put together, yet the whole arrangement of the valves offer much less obstruction than in any other reciprocating pump.

The Cornish pumps give at least five right angular turns to the water, and as many more in the valves, all of which are abrupt, with little or no curve. They also give four changes in the form of the volume of the water in passing through the pipes and pumps.

The Brooklyn pumps, and the new ones at Cincinnati and Chicago, and the Worthington pumps, have as many right angular turns and changes of the form of the volume as the Cornish pumps.

## DESCRIPTION OF THE PARTS.

The Steam Cylinder.—The steam cylinder is thirty-eight inches diameter, and of a length to allow eight feet stroke of piston; the general thickness of the metal is one inch; the cylinder bottom is cast separate, and the whole is covered with plaster of Paris and ashes, and cased with black walnut.

The steam piston is of cast-iron, fitted with metallic rings and springs. The piston-rod is of steel, four inches diameter.

Steam Chests.—The steam chests are arranged for single valves, and the valve gear for an adjustable cut-off; the valve and seats are of brass, and together with the connecting pipes are cased and covered similar to the steam cylinder; the pipes have a provision for expansion.

Working-Beam.—The working-beam is of cast-iron, and arranged for single link connections to the steam cylinder, pumps, and crank pin. The beam pillow blocks are fitted with brass boxes.

Main Column.—The main column, which is also used for an air-vessel, has an average thickness of metal in the body of one and one-quarter inches, with heavy flanges and brackets.

The lower part of the main column forms the condenser.

Shaft.—The main shaft is of wrought-iron, nine inches diameter at the journals and crank eye.

Fly-wheel.—The fly-wheel is of cast-iron, sixteen feet diameter, and weighs twelve tons.

Air-Pump.—The air-pump is not lined, is twenty-seven inches diameter and thirty-four inches stroke, and one inch thickness. The foot valve seat is fitted to the lower end of the pump, and the delivery valve is a wooden dome, with wooden face. The bucket and foot valve seats are of brass; the valves of pure rubber and the bucket rod of iron.

Water-Pumps.—There are two single-acting water-pumps, twenty-eight inches diameter, adapted for a stroke of four feet eight inches; the thickness of the metal is one and one-half inches.

Water-Pistons and Valves.—The water-pistons or buckets are of brass, and fitted with lignum vitæ packing; the valves are brass, recessed for and fitted with pure rubber at their faces; the suction and delivery valves have brass seats of the same diameter as the bore of the pumps, and are fitted with brass valves, constructed similar to those of the water-buckets.

Suction Pipes.—The suction pipes are of cast-iron, twenty-four inches diameter, fitted with strainers at the bottoms; the thickness of the metal is one and one-half inches.

Delivery Pipes.—The delivery pipes are of cast-iron, sixteen inches diameter; the thickness of the metal is one and one-half inches; they are fitted with expansion joints.

Boilers.—There are two cylindrical, tubular boilers, six feet diameter and eighteen feet long, each having thirty-five tubes, five inches outside diameter, and eighteen feet long; the shell is ⅜ inch thickness, heads ⅝ inch thickness, the tubes No. 9 thickness. The boilers were tested with one hundred pounds hydrostatic pressure per square inch, and are fitted with steam domes three feet diameter and eight feet high; they are set in brickwork, and so arranged as to pass the fire under the boilers, back through the tubes, thence over the upper parts of the boilers, and by a flue to the chimney.

The furnaces are five feet long and five and one-half feet wide.

## CALCULATION OF THE STRENGTH OF THE PARTS.

**Boiler.**—Longitudinal rupture, from the formula:

$$P = \frac{T\,t}{R} \qquad T = \frac{P\,R}{t}$$

$P =$ the pressure in pounds per square inch.

$t =$ thickness of plate.

$T =$ the tensile strength.

$R =$ radius of boiler in inches.

We have, where 30,000 pounds is taken as the tensile strength, and a modulus of 5 is assumed,

$$P = \frac{6000 \times .375}{36} = 62 \text{ pounds safe pressure.}$$

$$T = \frac{25 \times 36}{.375} = 2400$$

$$M \text{ the modulus} = \frac{30000}{2400} = 12.5.$$

Transverse rupture, from formula,

$$P = \frac{2\,T\,t}{R}.$$

Which gives values twice as large as in the previous case.

**Steam Dome.**—Longitudinal rupture from the preceding formula, after substitution we have,

$$P = \frac{6000 \times .375}{18} = 124 \text{ pounds safe pressure.}$$

$$T = \frac{25 \times 18}{.375} = 1200.$$

$$\text{The modulus } M = \frac{30000}{1200} = 25.$$

**Cylinder.**—Longitudinal rupture. From Whilden, on the Strength of Materials, page 11, we have the following formula:

$$t = a + \frac{R \times P}{T}$$

$a =$ thickness necessary to insure good casting.

$R =$ radius of cylinder.

$P =$ initial pressure of the steam.

$T =$ tensile strength of the material.

Taking the tensile strength of cast-iron at 15,000 pounds per square inch, and assuming a modulus of 5, we have,

$$t = .5 + \frac{20 \times 19}{3000} = .5 + .13 = .63 \text{ inches,}$$

the thickness of metal actually required to sustain the pressure, if the tensile strength of cast-iron was 3,000 pounds per square inch.

The thickness of the cylinder is 1 inch, substituting in the formula we have,

$$T = \frac{R \times P}{t} = \frac{19 \times 20}{1} = 380.$$

$$\text{The modulus } M = \frac{15000}{380} = 39.$$

**Liability of the Head to Blow off.**—The pressure exerted on the head equals its area multiplied by the pressure per square inch $= 1134.11 \times 20 = 22682.2$, say 23,000 pounds.

To resist this there are 4 bolts each 2½ inches diameter, or 3.97 square inches area.

$3.97 \times 4 \times 50000 = 794000$ pounds, the total amount of resistance.

$$\text{The modulus } M = \frac{794000}{23000} = 34.$$

**Piston-Rod.**—From the formula in Wilden,

$$W = \frac{f\,A}{1 + c\left(\frac{L}{D}\right)^2}$$

$f = 36{,}000.$

$c = \frac{1}{3000}.$

$A =$ area of piston-rod $= 12.56$.

$L =$ length in feet $= 10$.

$D =$ diameter in inches.

$$W = \frac{36000 \times 12.56}{1 + \frac{1}{3000}\left(\frac{10}{4}\right)^2} = 350000 \text{ nearly.}$$

$$\text{The modulus } M = \frac{350000}{23000} = 15.$$

**Air-Pump.**—The air-pump is 27 inches diameter and 34 inches stroke. Number of strokes per minute 12½.

27 inches diameter $=$ 572.5 square inches area $=$ 3.97 square feet area.

36 inches $=$ 2.83.

$3.97 \times 2.83 \times 12.5 = 140.4$ cubic feet per minute.

Tredgold says, the air-pump has to remove from the condenser at each stroke $\frac{1}{30}$ of the volume of the steam cylinder of air and vapor.

Volume of steam cylinder $= 7.88 \times 8.2 = 64.6$; $\frac{64.6}{30} = 2.1$ cubic feet at each stroke, or $2.1 \times 12.5 = 26.25$ cubic feet per minute.

From Bourne, page 181:

A cubic inch of water raised into steam, requires 22.34 cubic inches of water at a temperature of 50 degrees to condense it; hence 1 cubic foot of water forms 23.34 cubic feet of condensed water.

The boiler evaporates .7 cubic feet per minute, $23.34 \times .7 = 16.338$ cubic feet per minute.

$16.338 + 26.25 = 42.588$ cubic feet of air, vapor, and water to be removed from the condenser per minute.

**Water Pumps.**—To deliver 2,000,000 gallons in 10 hours. Two single-acting pumps 28 inches diameter and 4 feet 8 inches stroke; number of strokes per minute 12½.

28 inches diameter $=$ 615.75 square inches area $=$ 4.27 square feet.

$4.27 \times 4.66 \times 12\frac{1}{2} = 248.6$ cubic feet per minute.

1 cubic foot $=$ 7½ gallons.

10 hours $=$ 600 minutes. $600 \times 7\frac{1}{2} = 4500$.

$248.6 \times 4500 = 1{,}118{,}700$ gallons delivered by each pump in 10 hours.

Both pumps will deliver twice this amount, or 2,237,400 gallons.

| | |
|---|---|
| | 2,000,000 |
| Leaving for leakage ... .................. | 237,400 gallons, or $11\frac{3}{10}$ per cent. |

## MECHANICAL EFFECT OF ENGINE.

**Nominal Horse Power.**—Manchester rule, $NHP = \frac{a}{23}$.

$a$ = area of piston $=$ 1134.11.

$$NHP = \frac{1134.11}{23} = 49.$$

Watt's rule $NHP = \sqrt[3]{s \times d^2}$.

$s$ = length of stroke in inches.

$d$ = diameter of cylinder in inches.

$$NHP = \sqrt[2]{96 \times 1444} = 51.5.$$

**Actual Horse Power.**—Haswell, page 605:

$$HP = A \times \overline{P - f} \times 25\, r$$

$A$ = area of piston in square inches.

$P$ = mean effective pressure in pounds per square inch.

$f$ = friction of engine in all its parts.

$s$ = stroke of piston in feet.

$r$ = number of revolutions per minute.

$$\text{Clearance} = \frac{96 + 2.4}{32 + 2.4} = \frac{98.4}{34.4} = 2.9.$$

Hyploy 2.9 $= 1.065$, $1.065 + 1 = 2.065$, $\frac{2065 \times 34.7}{2.9} = 24.71 = P$.

$f = 1.5 + \overline{24.71 - 15 \times 05} = 2.66$.

$\therefore HP = 1134.11\ \overline{24.71 - 2.66} \times 2 \times 8 \times 12\frac{1}{2} = 5001425$ feet pounds.

## SUMMARY OF RESULTS.

In the computation of the strength of the different parts of the machine, we find the moduli varying from eight to forty. This shows that none of the parts are overstained, and that the load might be considerably increased without danger.

We also find the capacity of the pumps ample, as they allow $11\frac{3}{10}$ per cent. for leakage. This amount would not be reached unless the valves were very much worn. The best moving pumps and valves lose about four per cent. when in their order, and increase up to ten per cent. as they become worn.

The velocity of the steam piston is two hundred feet per minute; this corresponds very nearly with that determined by practical mechanics for engines of this size.

The velocity of the pump piston is 116⅔ feet per minute, or fifty-eight and one-third per cent. of the velocity of the steam piston. This corresponds nearly with that of the best arranged pumping machines in this country and in Europe.

The steam is intended to be used at a temperature which will give a pressure at its entrance into the steam cylinder of twenty pounds per square inch; and after adding the value of the expansion and of the vacuum, and deducting the friction of the machinery, it will give an average constant available power at the water piston, of twenty-five thousand pounds, or five million feet pounds per minute.

The average constant load of the water on the pumps, including that from the extra pressure produced by its friction at the velocity stated, is forty-one thousand five hundred pounds, or four millions eight hundred thousand feet pounds per minute.

The leverage of the beam gives an advantage to the steam pressure in the proportion of eight feet to four feet eight inches.

At the commencement of each stroke, there is resting upon the water piston the pressure due to the weight of a column of water of twenty-eight inches diameter and one hundred and thirty feet vertical height, which is equal to thirty-four thousand seven hundred and seventy-five pounds; and when this water has attained its average velocity of one hundred and twenty feet per minute, its pressure will be equal to forty-one thousand four hundred and sixty-two pounds.

The initial power of the steam on its piston, including its beam leverage, after deducting the other resistances, exerts a pressure of fifty-two thousand three hundred and sixty-two pounds against the column of water in the force main. This pressure continues for one-third the length of the stroke, and its surplus power beyond the resistance of the water is absorbed in giving momentum to the column of water (which weighs one hundred tons), and to the beam, rods, and pistons, weighing together about ten tons, and to the fly-wheel weighing twelve tons, with a leverage of two to one, and in the compression of the air.

In the second part of the movement, extending to a little beyond the centre of the stroke, the pressure begins with the same force as in the first part of the stroke, and ends with a pressure exactly equal to the resistance of the water.

On the last part of the movement (being nearly one-half the stroke), the pressure begins at just equal to the resistance, and terminates with the end of the full stroke at a pressure abont two-thirds of the resistance of weight of the water.

The surplus of power developed during the first half of the stroke (except a small portion of that absorbed by the fly-wheel, and that which is absorbed by the compression of the air), is exerted against the moving column of water in the pump main, and enables the waning power of the expanding steam on the last half of the stroke, to complete the stroke, and leaves a suplus in the fly-wheel of a little over one per cent. to turn the centres.

These pressures and resistances are approximately correct, but are only stated in this place in a general way, to describe particularly the absorption of the surplus power and its release.

The cut-off gear is adjustable, and will in practice be set so as to produce the effect desired, viz., to allow the piston to slow down at the end of the stroke, with only surplus power enough to turn the centre.

## CONCLUSION.

It will be observed by the preceding description of this pumping machine, that each step in its arrangement was arrived at by the consideration and application of certain well-known principles, and that on the completion of the plan it did not materially differ in general principles and form from one of Watt's most approved plan of pumping engines, made eighty years ago, although the author of this plan probably did not know of the process of reasoning by which this great Father of the profession arrived at his conclusions.

The characteristics of this pumping machine are:

*First.* That it gives the most appropriate velocity to both the steam and water pistons.

*Second.* That it avoids all unnecessary changes in the volume and direction of the water.

*Third.* That it applies the expansion of steam to its most useful extent, and so as to produce the most natural movement of the water during the different parts of each stroke, and restores almost the whole of the momenta acquired in the first half, during the completion of the last half of the stroke.

*Fourth.* That it is a well-balanced machine, of extreme simplicity and accessibility to all its parts.

*Fifth.* That it is massive and strong, with none of its parts liable to undue wear or strains. and consequently of great cheapness in construction and maintenance.

Such a machine ought to show a duty at least equal, and probably superior to that of any other pumping machine in this country, and will doubtless compare favorably with the best ones of Europe.

The most recently built pumping machines in the United States are of the Cornish type, or those with direct double-acting pumps.

Those in England are generally either Cornish engines or vertical beam engines, with two cylinders and a single pump arranged with a plunger, and also with a valved piston. The Cornish machines have long maintained their character for giving a high duty. They are more expensive in construction and more difficult in management than any other.

The plunger and piston pump also conforms nearly to the governing principles which have been stated.

The Brooklyn Pumping Engine has a double-acting steam cylinder and two peculiar double-lift, single-acting pumps, and loaded pump rods like those used in the Cornish engines.

The Cincinnati machine is sixty feet high, with the water-pump, air-pump, and steam piston rods in one continuous vertical line. The pump is double-acting, and the machine is amenable to all of the objections which have been before stated against direct and double-acting pumps, and also to the difficulty of maintaining its three pistons and four stuffing boxes in line.

The Chicago machine is composed of two distinct pumping engines, coupled at right angles with two direct double-acting pumps. To it also apply all of the objections stated to other direct-acting pumps; and also the further objection produced by the coupling of the two engines at right angles, which carries each of the pump pistons over its centre at the same velocity that it has in the other parts of the stroke, and forces the piston at the commencement of the return stroke with its maximum velocity against the water, which is flowing also with its maximum velocity in the pump chamber.

The Washington double-pumping machine has all of the objections which have been made to the Chicago machine, as well as those arising from the connection of three cylinders in one direct line, and the friction and wear of each of the three pistons arising from their horizontal position.

From the preceding discussion of the subject, it will be seen that the pumping machine which has been herein reviewed is more free from the objections which are above stated to the several types of modern engines, and conforms more strictly to the principles which have been enunciated, than any of the machines except the Cornish, to which in these respects it is fully equal, and to which it is superior in economy of construction and the safety and cost of maintenance.