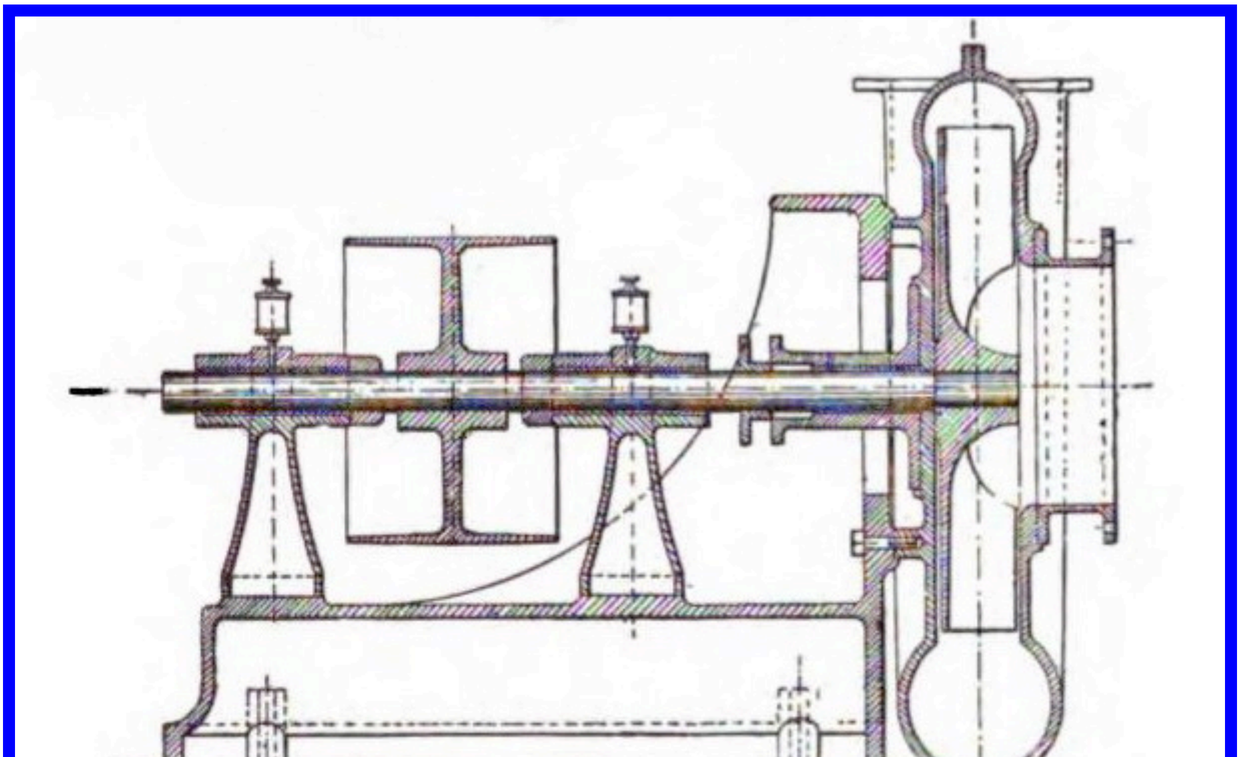
PUMPS & PUMPING MACHINERY
1500 BC-1960

Barr on Pumps



1899

PUMPING MACHINERY.

A PRACTICAL HAND-BOOK

RELATING TO THE

CONSTRUCTION AND MANAGEMENT

OF

STEAM AND POWER PUMPING MACHINES.

BY

WILLIAM M. BARR,

MEMBER AMERICAN SOCIETY MECHANICAL ENGINEERS.

WITH UPWARDS OF TWO HUNDRED AND SIXTY ENGRAVINGS, COVERING EVERY ESSENTIAL DETAIL IN PUMP CONSTRUCTION.

PHILADELPHIA:
J. B. LIPPINCOTT COMPANY.
1899.

PUMPING MACHINERY.

CHAPTER I.

INTRODUCTION.

THE art of raising water must of necessity have been one of the first of the mechanic arts to engage the attention of man, for no progress in civilization can be had without a convenient and ample supply of good and wholesome water. The earliest water-supply must have been the permanent springs and water-courses; but the growth of population, the increase in wealth, and a higher civilization required a broader development of the land, and it was during this period of development that the ingenuity of man was exercised in originating schemes and appliances for the lifting and distribution of water; but of the origin and early history of this art we know nothing.

It is not probable that any satisfactory device for raising water is lost to us, although its history has long since been forgotten, the fact of utility has been the very means of its preservation; nor did the great invasions and conquests of the ancient world affect unfavorably the development of this useful art, for water was alike essential to the conqueror and the conquered.

Machines for raising water admit of a great variety of forms, all depending upon the conditions of supply and delivery. The sources of supply are usually streams and wells; the ordinary delivery ranges from the simple lifting for irrigation to that of high service water-supply for cities.

A water-elevator has been defined (Knight) as a device for raising buckets from wells, and a pump as a device for lifting water by the motion of a piston in a cylinder.

Among the more important water-elevators are the following:

Archimedian screw,
Baling-machine,
Bascule,
Bucket-wheel,
Chapelet,
Dutch scoop,
Ejector,
Flash-wheel,
Flush-wheel,
Hydraulic belt,
Hydraulic ram,
Jantu,
Mental,
Noria,
Persian-wheel,
Picotah,
Scoop,
Scoop-wheel,
Shadûf,
Swape,
Turbine,
Tympanum,
Water-screw.

A partial list of pumps will include the following:

Bellows-pump,
Centrifugal,
Chain,
Chapelet,
Diaphragm-plunger,
Draining-pump,
Eccentric,
Ejector,
Elastic-piston,
Hydrapult,
Injector,
Pendulum,
Piston,
Plunger,
Rope,
Rotary,
Spiral,
Steam-jet pump,
Steam-vacuum pump,
Syringe,
Vacuum,
Water-ram,
Water-screw,
Water-snail.

By reason of the limited scope of the present work it will be impossible to illustrate and describe so formidable an array of water-raising machines included in the partial lists given above. The reader is referred to Knight's "Mechanical Dictionary" for definitions, and especially to Ewbank's "Hydraulics" for illustrations, description, and history of early and curious water-raising devices.

Atmospheric Pressure.—It must not be inferred that the ancients were unacquainted with the physical properties of the atmosphere, and that they did not take it into account in the development of their hydraulic machines. There is every reason to believe that they understood and applied certain principles relating to the atmosphere; for example, the ancient Egyptians understood and used the siphon at least fourteen hundred and fifty years before the Christian era, which clearly indicates that they were acquainted with some facts regarding the expansibility, as well as the compressibility, of the air; but this was only a partial knowledge, for it is not clear that the exact data regarding atmospheric pressure were known until the middle of the seventeenth century. So also the suspension of a liquid in inverted vessels by the atmosphere, such as the atmospheric sprinkling-pot, was known in the earliest historic times, or, at least, was well known in the fifteenth century B.C.

The Syringe.—Few ancient devices could be pointed out that have given rise to more important improvements in the arts than the primitive syringe. Its modifications exert an extensive and beneficial influence in society. As a piston-bellows it is still extensively used in Oriental smitheries. It may be considered as the immediate parent of the forcing if not of the atmospheric pump, in both of which it has greatly increased the comforts and conveniences of civilized life.

Suction is a word which has come down to us from a vast antiquity. The operation of sucking, as in the case of an infant, the sucking of poison from a wounded part by the application of the lips, are well-known illustrations. So also the raising of a liquid through a tube into the mouth. This operation has long been known as suction, and it was formerly believed that it was effected by some power or faculty of the mouth independently of any other influence.

Suction is simply a term used to denote the absence or the removal of the atmosphere, so as to permit the flow of the liquid; suction does not raise the liquid, nor does it help to raise it. The term sucker for the valve attached to the pump-rod in an ordinary lift-pump no doubt had its origin in the fancied similarity of its action as compared with that of the mouth.

An atmospheric pump is merely a contrivance placed at the upper end of a pipe to remove the pressure of the atmosphere there, while it is left free to act on the liquid in which the lower end is immersed. It is immaterial what the substance of the machine is, or what figure it is made to assume, for any device by which air can be removed from the interior of a vessel is or may be used as a pump to raise water; there will be required, however, two valves, one opening upwards and placed in any part of the pipe or in the machine itself, to allow the water to pass up through it, but none to descend; the other valve placed over an aperture opening outwards, through which the contents of the vessel can be discharged, and at the same time prevent the entrance of external air. Just how long it took the earlier inventors to determine the "limit of suction" is not known, but the exact weight or pressure of the atmosphere was not authoritatively announced until after the experiments of Torricelli, in 1608, and subsequently confirmed by Pascal forty years later. The fact was then fully established that an atmospheric pump must be placed within twenty-six or twenty-eight feet of the surface of the water to be lifted; but, owing to the difficulty in getting tight joints in the suction-pipe, this distance was gradually shortened until twenty-two to twenty-five feet was regarded as the practical or ordinary limit of suction.

Ewbank records a singular incident of a tinman of Seville, who undertook to raise water from a well sixty feet deep by a common pump. Instead of making the sucker play within thirty feet of the water, he made the rod so short that it did not reach within fifty feet of it. As a necessary consequence he could not raise any. Being greatly disappointed, he descended the well to examine the pipe, while a person above was employed in working the pump; and at last, in a fit of despair at his want of success, he dashed the hatchet or hammer in his hand violently against the pipe. By this act a small opening was made in the pipe about ten feet above the water, when, what must have been his surprise! the water instantly ascended, and was discharged at the spout.

This fact being published (1776) led to a reinvestigation of the subject, and instead of overthrowing the received doctrine of atmospheric pressure, more fully confirmed it. It was ascertained that the air on entering the pipe became mixed with water, and which, therefore, instead of being carried up in an unbroken column, was raised in disjointed portions, or in the form of thick rain. This mixture being much lighter than water alone, a longer column of it could be supported by the atmosphere; and by proportioning the quantity of air admitted, a column of the compound fluid may be elevated one hundred or two hundred feet by the atmospheric pump.

CLASSIFICATION OF PUMPS.

The easy and natural classification of pumps would be to divide them into three classes:

I. Lift-pumps,
II. Force-pumps,
III. Lift- and force-pumps,
} reciprocating or rotary.

These may again be sub-classified into—

Single-acting pumps,
Double-acting pumps.

And still further into—

Vertical pumps,
Horizontal pumps.

If pumps be classified according to their details of construction, the list would be still further extended into—

Bucket-pumps,
Piston-pumps,
Plunger-pumps,
Bucket- and plunger-pumps,
Bucket- and piston-pumps,
Piston- and plunger-pumps (known as the differential plunger-pump),
Rotary pumps,
Centrifugal pumps.

These names indicate a particular form of construction, and not a new or distinct classification, for each of these latter pumps must necessarily be included in the former. This latter classification is a convenient one, and has been adopted by the writer for his present use. It may be said that it is not an exact or scientific arrangement,—this much is admitted at the outset,—but it is the commercial one, and, therefore, in the direct line of every-day use.

The increasing subdivision in business enterprises, and the growing importance of pumping machinery as a part of the plant, would seem to call for another classification of pumps adapted for special uses ; for example, acids, alkalies, ammonia, beer, bilge-water, bleacheries, breweries, dye-works, drainage, fire-pumps, gas-works, etc. A mere catalogue of names, with suggestions regarding suitable pumping machinery for each, would occupy more space than could be given it in the present work, and it is doubtful even then if such a presentation would prove satisfactory because of the repetitions which must inevitably occur.

Pumps for General Service.—There is no subject in which it is so difficult to give advice in a general way as in pumping machinery, because each pumping plant has its own special peculiarities which must be considered, and which may not apply to any other pumping plant. There are two things, however, which come within ordinary practice, and if designs be made to accord with either or both, the greater part of pump-service will have been fully met.

The first one is, that if water-ends be made sufficiently strong to handle water at one hundred and fifty pounds pressure, fully eight-tenths of the ordinary run of pump requirements can be supplied. It is the common practice in designing water-ends for trade pumps to make the details of suitable size and form for this pressure. This will cover the highest fire-pressure, which is usually the severest test to which an ordinary trade pump is put. For small water-works the pressures rarely ever reach the one-hundred-and-fifty-pound limit, even when on direct service. For hydraulic elevator service the pressure seldom exceeds one hundred pounds per square inch, except in steel-works and other places where there is a general hydraulic system using very high pressures.

Tank-service usually calls for lighter pressures, ranging from twenty-five to fifty pounds, but it is not customary among steam-pump-makers to make any difference in the weight of the water-end; the size remaining the same, will require the same detail and workmanship, so that nothing but a small amount of cast iron would be saved, and that is not worth the cost of altering or making new core-boxes.

The second relates to steam-pressure, which does not in ordinary practice exceed eighty or ninety pounds, so that if a steam-end of a pump be designed for one hundred pounds pressure, factory, water-works, and other service will be amply provided for.

Combinations of such steam- and water-ends will, therefore, meet almost every requirement in ordinary hydraulic operations.

Pumps for special service for higher steam- and water-pressures, such as doubling either or both of them, will require new proportions. An increased steam-pressure will, in general, require nothing more than thicker castings and stronger bolting, the size of the ports, the distribution of steam, and other details remaining much the same. For the water-end it is often best to entirely change its form, and this usually occurs. Coupled with this higher water-pressure is, with few exceptions, a smaller quantity of water to be delivered. This is especially so in the case of hydraulic-pressure pumps, but is not generally true of pumping for mines.

Whatever the service, pumps must be able to work continuously without danger of breakage, and this with as little expenditure of power as possible. But there are other considerations than the mere saving of coal: a pump must be simple, easily managed, and certain in its operation, or it will fail to meet the requirements of its owner, who seldom knows anything about pumping machinery. The very large business now annually done in direct-acting single and duplex pumps can probably be traced directly to their meeting the above conditions.

CHAPTER XVI.

CENTRIFUGAL PUMPS.

A DEMAND exists for a pump with which large volumes of water may be quickly handled, such as in tanneries, paper-mills, print-works, dry-docks, etc. This water being liable to contain chips, bark, and other floating matter, makes it especially desirable that the pump be valveless,—a problem for which the centrifugal pump offers an almost complete solution. The construction of the centrifugal pump is exceedingly simple, consisting of a revolving fan having two or more blades, either straight or curved, attached to a revolving spindle, and fitted in a case or shell so constructed that the suction shall enter at the centre of the wheel, and the delivery placed tangent to the outer path of the revolving blades.

The recorded experiments relating to centrifugal pumps are few. Among these, two are favorably known to the writer,—one by Mr. R. C. Parsons,* England, and the other by Mr. W. O. Webber,† Lawrence, Mass,—the first relating more especially to the theory of centrifugal pumps, and the latter to their efficiency as compared with reciprocating pumps; the writer acknowledges his indebtedness to both of these experimenters for subject-matter used in this chapter.

Centrifugal pumps are by no means a modern invention, the crude idea of which probably dates as far back as the middle of the last century, when the mathematician

---

* Proceedings of the Institution of Civil Engineers. London, 1876. Vol. XLVII.

† Trans. Am. Soc. Mechanical Engineers. New York. Vols. VII. and IX.

Euler brought out a primitive form of centrifugal pump, an account of which he published in the Proceedings of the Academy of Berlin for 1754, but which never came into practical use. From that period many rotary and centrifugal pumps were invented, principally by French engineers, but none of them seemed to have yielded even a reasonably good efficiency. The first mention of a centrifugal pump at all to be compared with those of the present day is in the year 1830, when one was erected by Mr. McCarty in the navy-yard at New York, and some improvements were patented by him in the following year. The next epoch in the history of the centrifugal pump is the Exhibition of the year 1851, London, when the late Mr. J. G. Appold achieved a great success with his pump of trebling the efficiency obtained by any other exhibitor.

The experiments made with Appold's centrifugal pump showed that its efficiency mainly depended upon the form of the blades of the fan; and, further, that the best form was a curved blade pointing in the opposite direction to that in which the fan revolved. These were tried in comparison with two other forms.

TABLE XX.

APPOLD'S CENTRIFUGAL PUMP.

	Height of Lift in Feet.	Discharge in Gallons per Minute.	Revolutions per Minute.	Velocity of Circumference in Feet per Minute.	Percentage of Effect to Power.
With radial arms . . .	18.0	474	720	2262	24
With straight inclined arms	18.0	736	690	2168	43
With curved arms . . .	8.2	2100	828	2601	59
" " . . .	9.0	1664	620	1948	65
" " . . .	18.8	1164	792	2988	65
" " . . .	19.4	1236	788	2476	68
" " . . .	27.6	681	876	2751	46

From the above table it will be seen that as between radial blades and curved blades the increase in efficiency was more than doubled in favor of the latter; subsequent calculations and more exhaustive experiments show that nothing in connection with centrifugal pumps has been more clearly proved, both theoretically and experimentally, than that the blades should curve backward, and according to Thomson the general form of the curved blade is an element of great importance, and it is a necessary consequence of the arms being thus shaped that the water is driven through the wheel, partly by the action of centrifugal force and partly by the oblique pressure of the blades on the water. The ratio which each of these forces bears to the other varies even in the same pump, according to the proportion the speed of the pump bears to the height of the lift. When the lift is very small and the speed great, the water is expelled without having any considerable rotary motion imparted to it. In such a case the resistance to the outward motion of the water is so small that the oblique action of the blades is sufficient to expel it without giving it a speed of rotation at all approaching that of the fan.

In centrifugal pumps the main object is to pass the water through the pump with as little "whirling" velocity as possible, because the power thus absorbed is not again given out, and becomes a more or less hinderance to the flow. Designs vary so much that it is clear no settled opinion has yet been reached as to the best proportions for blades, nor yet as to the best proportions and best shape for the case which contains the revolving fan. Mr. Thomson recognizes it as a favorite idea with many designers of centrifugal pumps to contract the space between the sides of the fan at the circumference so as to make the area of opening through the fan uniform, and thus preserve a uniform radial motion of the water during the whole passage through the fan. The effect of this as well as of many other modifications was tested experimentally by Mr. Appold, and he found that it was productive of no increase of duty. Mr. Parsons, on the other hand, considers it a detail which affects the efficiency of the pump, but not to the same extent as the form of the blades, and says that "the old theory which Morin, Appold, and many others held, and which is still held in some recent books,—viz., that as long as the casing outside the fan is large enough it is immaterial what shape it is,—can be proved to be false both by theory and experiment."

The passages throughout the pump must be so proportioned as to have a gradually increasing velocity in the water until it arrives at the circumference of the fan, and then to have a gradually decreasing velocity until it issues from the discharge-pipe. This condition is effected by having a conical end to the suction-pipe, and, what is much more important, is to have a spiral casing surrounding the fan. The importance of this last detail, Mr. Parsons says, is shown most conclusively by experiments with both circular and spiral cases. The form of the casing should be an Archimedian spiral, which has the property that the water flowing round the case moves with the same velocity as that issuing from the fan. The casing should then gradually open out into the discharge-pipe.

TABLE XXI.

EXPERIMENTAL EFFICIENCIES OBTAINED BY R. C. PARSONS ON A 14-INCH REVOLVING FAN, 10-INCH SUCTION, AND 10-INCH DISCHARGE, MADE ON THE APPOLD PRINCIPLE.

Revolutions per Minute.	Gallons per Minute.	Lift in Feet.	Foot-Pounds.		Efficiencies. Per cent.
			Water Raised.	Indicated Power.	
392	1012	14.67	148,461	298,438	49.74
394	1108	14.70	162,875	317,158	51.35
395	1197	14.65	175,364	332,136	52.80
400	1431	14.75	211,073	374,954	56.20
405	1695	14.75	251,987	419,790	60.17
425	1108	17.20	190,576	388,316	48.97
431	1431	17.40	248,994	447,552	53.63
435	1695	17.60	298,310	486,050	61.37

This pump was placed on a floating scow to obtain as nearly as possible a constant lift; it was driven by a separate steam-engine, and the power was measured by a dynamometer.

There are two totally different conditions in which a centrifugal pump may be situated while it is rotating,—one in which it is revolving just fast enough to raise the water up to the discharge-pipe and no farther, and another in which it is revolving slightly faster, and is discharging water out of this pipe. In the first case there is only centrifugal force, which is produced by the water in the fan rotating, that maintains the column of water in the discharge-pipe. In the second case, this force is still produced, but in addition to it another, which may be called the force of impact, or in other words, the force with which the blades of the fan impinge against the water discharged by the pump.

The centrifugal force in the first case was calculated by Mr. Parsons to be as follows: Assuming that the fan is a cylinder of water; every particle of this water as it rotates exerts a force outwards from the centre; consequently the force exerted at the circumference, or that which maintains the head in the discharge-pipe, is the sum of the forces of all the particles from the centre of the fan to the circumference. This force is given in pounds per square inch by the formula

$$F = \int_0^R \frac{P x \, dx}{g} w^2 \qquad (1)$$

Integrating this expression

$$F = \frac{p R^2 w^2}{2g} \qquad (2)$$

p = weight in pounds of a column of water 1 inch square in section and 1 foot long.
R = radius of fan in feet.
w = angular velocity of fan.
g = dynamical force of gravity.

Now, since $R w = v$, where v equals velocity of circumference of fan, by replacing $R^2 w^2$ by v^2 in equation 2 it becomes

$$F = \frac{p v^2}{2g} \qquad (3)$$

Now, supposing that the head supported by the fan, while it is rotating with a tangential velocity v, be h, then the pressure at the base of the column is ph, but by the ordinary formula of dynamics

$$h = \frac{v^2}{2g}; \text{ therefore } ph = \frac{p v^2}{2g} \qquad (4)$$

thus by equations 3 and 4 $F = ph$.

Therefore a fan, when rotating, will support a column of water the velocity due to whose height is equal to the tangential velocity of the circumference of the fan. This conclusion is fully borne out by experiments, where corrections are made for the axle of the pump displacing a small quantity of water, and thus reducing to a slight extent the centrifugal force.

The Second Force exerted in this Case is that of Impact.—It is estimated by the maximum tangential velocity generated in the water passing through the fan, which takes place just as it is escaping at the circumference. The reason advanced that this force can be estimated by the tangential velocity produced is that no other force can produce this velocity.

The centrifugal force can only produce a radial force or radial velocity, but can in no case produce a tangential force or tangential velocity. This latter force can only be made use of by gradually reducing the velocity of the water issuing from the fan, and this condition is effected by the spiral casing and conical discharge-pipe, which can easily be calculated by multiplying v by cosine θ', the angle made by the blade of the fan at its outer extremity with the tangent to the fan; and subtracting this from V, the velocity of the circumference, the absolute tangential velocity of the water leaving the fan is obtained,—viz.:

$$v' = V' - v \cos\theta \qquad (5)$$

The head then due to this velocity is given by the formula

$$H_1 = \frac{v'^2}{2g} \qquad (6)$$

This, in other words, is the height that the water would rise supposing that there was no friction to impede it. Now, the circumferential force has been estimated in pounds per square inch; but by dividing it by 0.434 it is reduced to feet head of water. Then, by adding these two heads together, the theoretical height to which the pump lifts the water is obtained, —*i.e.*,—

$$H + H_1 = \frac{F}{.434} + \frac{v'^2}{2g} \qquad (7)$$

This theoretical lift is always greater than that deduced by experiment, and it is only in a perfect pump that these two lifts would coincide. Consequently, if the practical lift be divided by the theoretical lift, and the result multiplied by 100, the percentage efficiency of the pump is obtained.

Effect of High Speed of Rotation.—The faster the fan rotates, the lift remaining constant, the smaller is the centrifugal force. This seems to be a paradox at first sight, but the reason is evident. As the discharge increases, the velocity of the water in the casing more nearly approaches that of the water leaving the fan; consequently the efficiency of the pump improves, and the theoretical lift diminishes, and with it the centrifugal force.

A remarkable property of centrifugal pumps may be mentioned, which has been clearly shown by experiment, and that is, a small increase in the number of revolutions of the pump, when it has begun to discharge, produces a very large increase in the delivery. Thus, in Table XXI. the difference in discharge between experiments at 392 revolutions per minute and 405 revolutions per minute is 683 gallons per minute, and this with the small increase of only 13 revolutions.

In the table of the Appold centrifugal pumps the highest efficiency given is 68 per cent., and in the table of efficiencies resulting from Mr. Parsons's experiments the highest efficiency is given at 61.37 per cent., which is practically the same as that given by Mr. Webber in his reference to the Gwinne pump, tested in 1883, under 14.7 feet lift.

Experimental Tests of Centrifugal Pumps by Mr. W. O. Webber.—Mr. Webber's use of the term efficiency he explains as indicating the value of $\frac{\text{Water H. P.}}{\text{Indicated H. P.}}$ for such pumps as are driven by an engine direct, and does not, therefore, show the full efficiency of the pump, but that of the combined pump and engine. It is, however, a very simple way of showing the relative values of different kinds of pumping engines having their motive-power forming a part of the plant. Mr. Webber's tests were made with ordinary centrifugal pumps, such as are supplied to the trade in the regular course of business. The general elevation of a 5-inch, class B pump is given in Fig. 227, and in sectional elevation in Fig. 228. In

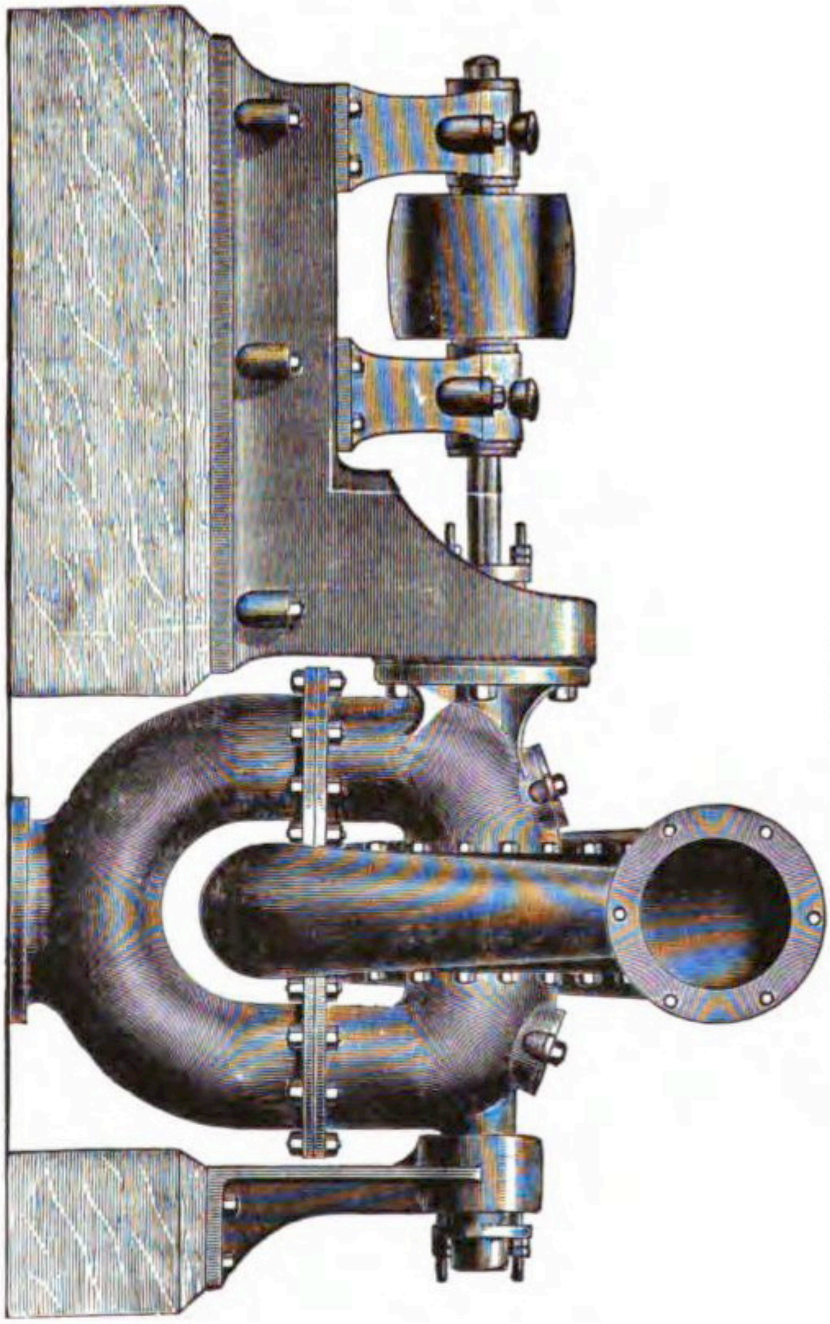


FIG. 227.

calculating the efficiency of the pump, the cubic feet of water passing over the weir, measured by the hook-gauge, being converted into pounds by multiplying by 62.5, is again multiplied by the height from the level of water in the tank when the pump is running to the centre of the discharge-pipe, and the foot-pound so obtained, divided by 33,000, equals the water horse-power being developed.

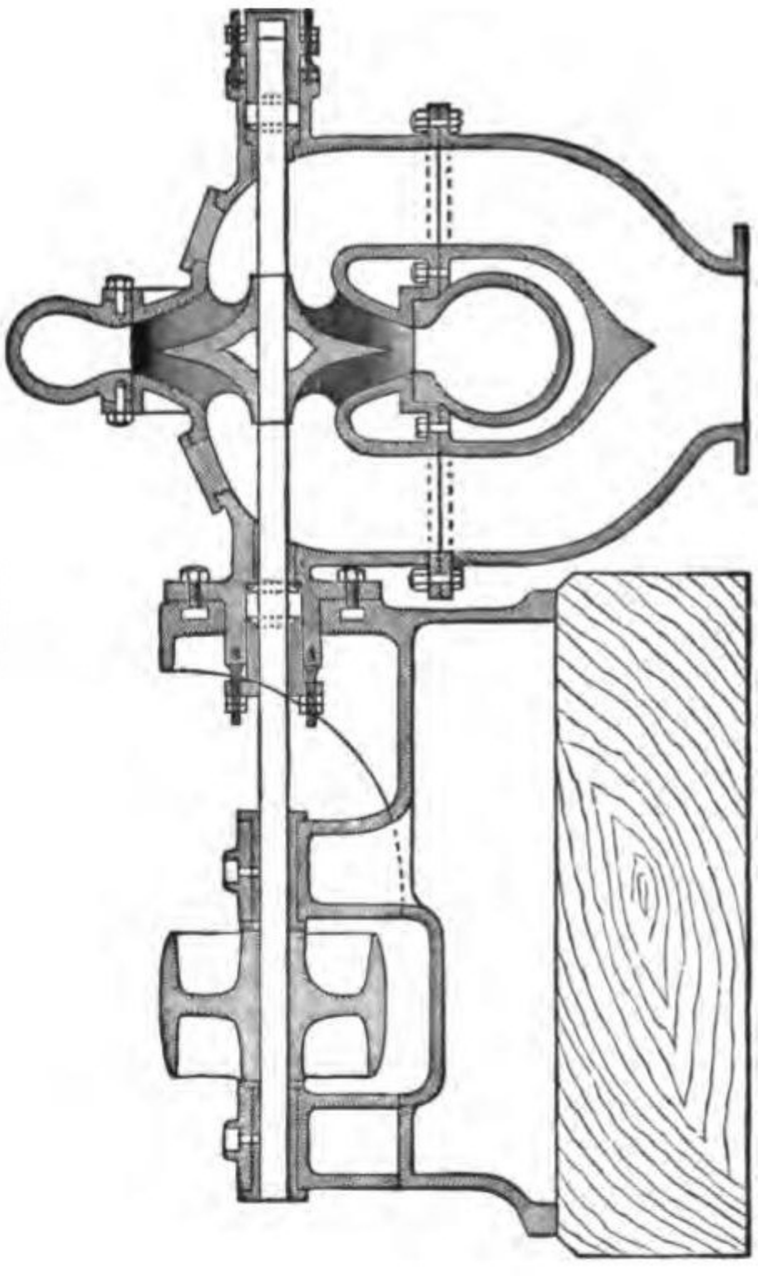


FIG. 228.

Morris Machine-Works Centrifugal Pump.—A sectional elevation of a centrifugal pump by the Morris Machine-Works, Baldwinsville, N. Y., is shown in Fig. 231. This pump has a central suction-opening, the revolving disk is furnished with curved blades for imparting to the water a proper direction and velocity into the spiral chamber which surrounds the circumference of the revolving blades. The makers have adopted this design in common with other first-class builders,

FIG. 231.

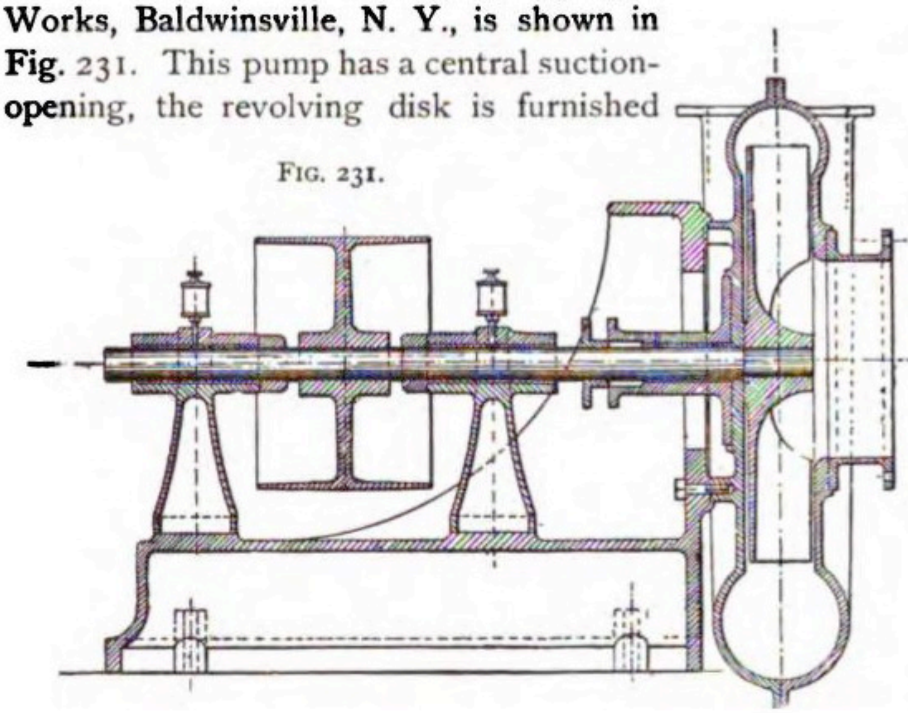


FIG. 232.

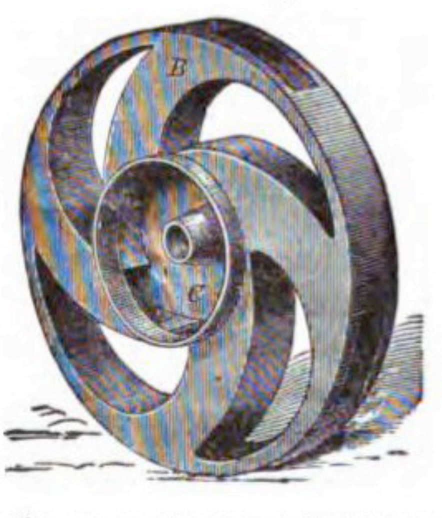


FIG. 233.

as it was experimentally shown long ago that spiral castings closely surrounding the fan gave the best results.

Several designs for pistons, as these revolving blades are sometimes called, have been tested in actual service, from which three have been selected for illustration.

Fig. 232 represents a hollow arm piston, which is used in their standard pumps in size No. 4 and above. It is the one on which the fame of the Heald & Sisco pump is mainly based, and is their special favorite for raising water or any thin fluid not too much encumbered with stringy or tenacious matter. For over a quarter of a century it has held the lead against all comers.

FIG. 234.

Fig. 233 represents a concave arm wing, which they use in their No. 3 standard pump and smaller sizes. It has proved itself very efficient. For raising half stuff in paper-mills and stringy material often found in tan liquor, they recommend the wing as being the best. In pumping very thick material they use a wing with two arms only.

The piston shown in Fig. 234 is of their own invention, and has been used upwards of six years in their special sand- and dredging-pumps. It is very heavy, has large openings, and is very efficient. By its use material taken in it is deposited on pump-scroll, thereby preventing wear on the pump-sides. All sand- and dredging-pumps of their make are fitted with it.