available in Wales and in America is almost unlimited, and very much of that raised is now unsalable, merely because it is too small to be used. In Pennsylvania, according to Mr. Bell, one-fifth to one-half of the material brought to the surface in the anthracite collieries is thus thrown aside, partly shale and stones, but chiefly small and dust coal, perfectly bright.

ON TURBINE WHEELS.

By EMILE GEYELIN.

[Read before the Franklin Institute, March 5th, 1876.]

The subject to which I would call your attention this evening, is that of *Turbines*.

Before defining the meaning of the word Turbine, allow me to say that "water," the element made use of, having a given weight, 62½ lbs. per cubic foot, becomes a source of power when that weight, owing to the topographical formation of the country, can reach a lower level; and that power, is proportionate to the quantity of water, in a given time, as well as to the height it is allowed to fall—power being the product of weight multiplied by velocity.

The means by which water is made to impart power, are, as you all know, water wheels (and I might add water engines), of which undershot, breast and overshot wheels form one class, and turbines form another; the distinguishing features of these wheels being, that whereas in the first class, the water is allowed to act more by its weight, in the turbine class, it is allowed to act more by the speed due to the fall under which it operates. The term turbine is derived from the Latin "*turbo, turbinis*," a whirl or top. It would imply, and, in fact, I have seen it often stated, that it means water wheels turning on vertical axes; but it is not necessarily so, since they are, especially when brought to use under high falls, coupled together on a horizontal shaft, and in that position produce satisfactory results; in which case, the water being admitted in opposite directions, neutralizing the great pressure that would otherwise be exerted on the step.

A review of the development of the *turbine* is a most interesting one; but we do not find any gigantic strides, such as the introduc-

tion of the railroad and the telegraph has made in the first half of this century. Still we can admire the final results, and see that through the patient labor of years, step by step, man has learned to avail himself of nearly the whole of nature's power in water; and with such certainty, too, that the greatly accumulated force can be relied upon with the same confidence as the daily rising of the sun.

Thousands upon thousands of our fellow beings derive a livelihood through its agency, and its effect upon the wealth of a people can be read in the plainest of language by looking at New England to-day. Holyoke, Lowell, Lawrence, Manchester—those young giants whose wealth is wholly created by water power, as developed by turbines, are but a fraction of what New England has already accumulated from its vast resources. Large amounts lie yet dormant in her streams, to be called into usefulness by her future engineers and capitalists.

Let us now follow the gradual development of the water wheel; at best, we can but slightly touch a subject of which volumes may be profitably written.

FLUTTER AND UNDERSHOT WHEELS.

The most primitive structure, to be found in the backwoods, far from any human centres—the Flutter wheel—seems like the first seed. Water may be plenty, but the means are scant. The noise of the water as it splashes on the rudely shaped buckets, will attract you towards it. Most likely, in a picturesque spot, you will find it, perched on moss-grown rocks, a slender axle holding a frame, to which are secured a few plates. No formulæ laden with Sinus-Cosinus—cube root or other algebra—have given direction to its simple form. Shall we value it less? Let the tourist say, who, in the fragrant atmosphere of its surrounding pine and hemlock, has watched its unskilled efforts to shape a few boards. Near akin to the flutter wheel we have the undershot wheel; more pretentious in its fitting apron, whereby less gamboling of the water is allowed, as it comes dashing along. Look at the straight plates! Note how the water strikes them unprepared, to be left free a few moments later to continue its downward course! Are you surprised when told that one-third of the *vis viva* is all that these wheels develop? At this step science lends its help. First note how it bends the bucket, into flat surfaces at varying obtuse angles; then to the graceful curve of the “Poncelet wheel.” Here are no sudden shocks;

the plates quietly receive the pressure, and like a kind friend, hold the water in their folds to the very last. As a consequence, as high as sixty per cent. of force of the water has been developed by these wheels. The undershot wheels are adapted to low falls, and specially where slow motion is required, such as for the purpose of forcing air or water; but even in these conditions the turbines gradually take their places.

OVERSHOT AND BREAST WHEELS.

Many, no doubt, can remember when no other kind of water wheels would have found approval; and this day, for a small varying stream, what can give better returns than the slow, patient overshot wheel, waiting for the water as it comes filling bucket after bucket, and turning round when ready with its well filled side? It is not in this puny capacity, however, that the merits of the overshot or breast wheel should be estimated. Years ago many a stately factory was propelled by them. But valuable as they are in their application to the falls varying from twelve to sixty feet, they have objectionable features which their rival, the turbine, has not; they are therefore fast losing ground.

Let us examine these objections. We have, for instance, the comparatively large size, especially where a large power is required in a concentrated form, such as the propelling of a large cotton or woolen mill. Again, the fact that for the most cases wood is employed in their construction, which renders them short-lived and liable to many stoppages and repairs, we have also the necessity of having them housed in winter to prevent the ice from forming on their buckets; and last, but not least, we have as an objection, the loss of power by friction, created by the changing of their slow motion to the high one of the main shaft, which in most mills amounts to an increase from ten to twenty fold. All these objections are common to both the breast and overshot wheels, but the breast wheel presents comparative advantages over the overshot, which renders the preference for the turbine over the former, less marked.

Take, for instance, a stream wherein the water level varies; the breast wheel, with the arrangement of gate, can adapt itself more readily than the overshot wheel. When the upper level falls say eighteen inches, it draws from the lower gate; whereas the overshot wheel, unless originally constructed with a pressure greater than

necessary in the ordinary stages of the stream, will not be able to receive as much water as needed, owing to the reduced pressure over the gate. Another advantage of the breast wheel is that the water, as it leaves the wheel, is forced away, whereas the water, as it leaves the overshot wheel, is, to some extent, drawn under—thus submerging the buckets to some extent. In the overshot wheel, also, much of the water leaves the wheel before the lower level is reached, and therefore its developed duty is proportionally lessened.

Though overshot and breast wheels are not to receive our special attention on this occasion, I have dwelt somewhat at length on their main features, so as to be better prepared to review the second class of water wheels, namely :

TURBINES.

How long water wheels revolving on vertical axes, or, to speak more properly, water wheels depending more on velocity than on gravity, have been in use, I am unable to say ; it is quite certain, however, that fair specimens were left in Spain by the same people who left the Alhambra and other architectural wonders. Coming to more recent times, Belidor, the famous hydraulic engineer, a century and a half ago, in describing the fountains of Marly, amongst other kindred subjects, gives us descriptions and plans of water wheels belonging to this class.

Until the beginning of the present century, the record of advance made in the construction of turbines, is not worth stating ; but the earlier years of the nineteenth century exhibit the fruit of patient labor, as shown in the Fourneyron turbine. This turbine was improved, both in detail and in efficiency, by two of New England's honored sons, Uriah H. Boyden and James B. Francis—the former of whom can be considered its introducer into the mills of the United States. The perfection of their work rendered possible the great accumulation of power, whereby so many human hives are enabled to labor with profit to themselves, and to change the rocky hills into green and enlightened homes.

To state that the Fourneyron turbine was the only one of any merit, even a quarter of a century ago, would not be correct, since formidable rivals, especially those offering the advantage of smaller cost, soon made their appearance, and year by year since, these new, or fancied new, applications of the water, turned up ; until now, the turbine family is so large that its very names become bewildering.

In a theoretical point of view, matters become much more simple, since many of the turbine wheels known to the public are but combinations, and sometimes simply poor imitations of the parent stock.

For the purpose merely of tracing the analogy of the different kinds of turbines, I should like you to note that in the simplest form, a jet, and in more perfect forms, a series of jets, gradually prepare the water to strike the plates of the revolving wheel. It is in the perfection of the direction of these jets, and the corresponding area of a section of them to the area of the openings for discharge in the revolving wheel, that the main advantage of a turbine lies. The better class of turbines embody the principle of reaction, whereby an additional force is obtained.

The *Scroll*, *Reynolds*, *Trips* and *Parker* wheels illustrate the principle of a single jet. The water is led to the wheel through a contracted channel, and by increased velocity, strikes the plates of the revolving wheel. The *Scroll*, *Reynolds* and *Trips*, by the eccentric form of the casing, are able to act on the greater part of the periphery. The additional velocity to reach the extreme points, created by the contraction of the inlet, must always be obtained at the sacrifice of power; since the maximum effect of the water, can only be obtained when the full pressure due to the fall is brought into action at the first point of contact with the wheel which, must be so constructed and speeded that the water will leave the wheel with the minimum of velocity. The wheels above named, can *not* thus lay claim to high duty; from the simplicity of their construction, and especially where great economy of water is *not* necessary, they are much used. They are the pioneers to prepare the way for a more economical class of wheels to take their places.

Before speaking of the wheels where a series of jets are used in connection with the reaction principle, I would call your attention to the wheel acting *solely on the reaction principle*. In its primitive form it is known as *Barker's* wheel. A hollow, upright tube, through which the water is led to two arms, near the extremities, and on the sides of each arm are openings for the escape of the water; this simple construction comprises all the component parts of a *Barker's* wheel. A better form of this wheel, made with a closer application of hydraulic laws, becomes the "*Scotch motor*," in which the water is brought in an ample tube to two gradually diminishing and gracefully curved arms, whereby the water is allowed to retain much of

the pressure due to the difference of level under which it operates, and thus produce results which render it a most desirable motor; particularly where a constant changing of power is desired. The most successful application of that class of motors is at the Morris Canal, where they are used to propel the winding apparatus whereby canal boats are raised and lowered. Their construction is so plain that they proved most durable under quite unfavorable circumstances.

This reaction or retrograde force is thus the *additional* force whereby the highest returns of the water have been obtained. The first one to apply the double sources of power, *impact* and *reaction*, was Fourneyron.

Fig. I.

The turbine represented on the screen (Fig. I) is an exact copy of one built by Fournayron himself, 40 years ago; were I able to give you on the same screen the same class of turbines as constructed by Boyden & Francis, you could not avoid admiration for the thoroughness of their researches in finding, applying and perfecting of curves, and for the mechanical appliances, whereby the water is divided and prepared, from which curves and appliances were derived those astounding results (92 per cent.) of the total efficiency of the water power; that is of what power it would require to replace the water

used in propulsion back again in the basin. Notice the avoidance of sudden change of direction of the water, which, you will observe, is brought in a spacious conduct, whereby no great velocity is created: Standard velocity being from 2 to 3 feet per minute, nearly all is saved for the time of action on the wheel; from the base it is led by well formed cylindrical curves, secured on a stationary disk, to the plates of the movable wheel: The angle at which the water leaves the guide plates is calculated to strike the plates as near the tangent as possible: The angle is in the best wheels from 14° to 15° to the tangent, which becomes the angle on which the force is applied: By a gradual contraction of the space between the plates of the revolving wheel, the water is brought to the point of discharge, which is so arranged as to direct its retrograding force so as to bring the resultant force at a still more

reduced angle to the tangent: Careful computations make the ratio of forces as 8 is to 2.

Fig. II.

with this draft tube can be placed between both levels that constitute the fall, and produce the same result as if the turbine were placed at the bottom of the fall. Where it is not desirable to make deep excavations, this application of draft tube becomes valuable. Before going any further, I would state that all downward and inward discharge turbines, invented since, are making use of this feature.

The action of the water is somewhat different in the Jonval from what it is in the Fourneyron. A series of carefully prepared plates prepare the water for action, by directing it from the perpendicular to an angle of 16° with the horizontal surface when it is brought in contact with the plates of the revolving wheel, which plates are so placed as to receive the entering water as favorably as it is received by a Fourneyron wheel, but, instead of the water discharging outward, in the Jonval turbine it discharges downward. As usual with all downward discharge wheels, the *Jonval* has the merit of compactness—and in connection with the fact of being able to place it in any position between the two levels, makes it a very desirable hydraulic motor.

Let us now pass in review the remainder of the turbines most favorably known. 1. The charts represent the Swain, the Liffel, (double), the Risdon, the American, and the Excelsior. All these wheels, either discharging inward or outward, make use of the double action of impact and reaction, and were they all constructed by the same mechanical engineer, very little difference would be found

in the return of power from any given fall and quantity of water. The principal cause of loss of efficiency is to be found in the want of proper mechanical and engineering skill in adapting any particular wheel to the conditions under which it is to work, and specially so is the operation of gate or gates wherewith to open, close or regulate the quantity of water to be used. For the purpose of facilitating the comparison, I have shown the sections of wheels in cross lines, and of the gate in solid blast.

When performing an equal duty with an invariable supply of water, the gate of a turbine is used merely to start and stop. This condition, however, seldom occurs. Either the resistance varies, or the head, or height of column, of the water varies; and there are two modes of overcoming these variations. The first is to have a series of turbines, sometimes of varying power, connected to a general shaft, and thus connect or detach a turbine as wanted. This plan is certainly good, but often for want of space, or with the view to simplicity and compactness, it is desired to obtain the same results with one turbine. The second mode is that of closing or opening the gate or gates, and thus regulate the supply of water to meet the variation of head or the variation of resistance, or the effect of both variations combined. It stands to reason that the turbine which retains the two elements of power in their greatest perfection, is the one that comes nearest to that desideratum of working the best results under the above named variations. The gate of the Fourneyron turbine, you will observe, is a ring closing between the guide and movable wheel. The effect of this gate on the stream of water must be bad, since it brings the water by an abrupt closure or stoppage, into a flat, thin sheet, which, after passing beyond the gate, is left free to enlarge in thickness, on its way to the outer periphery, with not enough pressure left to act upon the wheel. Of course it would be possible for the makers of the Fourneyron turbine to construct the outer, movable wheel in flat divisions, like a series of separate wheels, one upon another (in place of one wheel, as generally made), when each division of the wheel would only receive water as the gate is elevated; but this construction has not heretofore been used by them.

The *Swain turbine* (Fig. III), you will note, has a better gate than the Fourneyron, since it brings the water between flat surfaces in any position it is put, but it is subject to the same objection as the Fourneyron gate, in not proportionally closing the movable wheel.

Fig. III.

Fig. IV.

The *Liffel* wheel (Fig. IV) presents the same feature as the Swain, of directing the water between the flat, though contracted, passage ways to the point of action, but with it also a corresponding contraction is not established in the movable wheel. The same remarks may be applied to the American turbine (Fig. V), and the *Excelsior* (Fig. VI).

Fig. V.

Fig. VI.

These conditions of imperfect action of the gate as usually applied to turbine wheels have led me to adopt a plan of gate for the *Jonval* turbine, which is here represented. It will be noticed, Fig. VII, that the division of the water, in halves or in thirds, is com-

Fig. VII.

variable quantities of the water, the plan was a most unsuitable one, as it removed the point of contraction from the wheel altogether, and merely made a resistance to the flow of water beyond it.

I will close my remarks on turbines by alluding to one of the most interesting features of these water wheels—it is their practical application to any height of fall. I have seen the famous turbine of St. Blasien, made by Fourneyron, operating under 350 English feet fall, giving 73 horse power, which is so well known to readers on this subject of turbines; but as a parallel example to this one, I desire to record one made by me, in 1854, for Saltillo, Mexico, which was a double turbine (that is a turbine receiving water *between* two movable wheels on the same shaft, which counterbalanced each other, and avoided the necessity of resisting the thrust from the head of water) for 160 feet fall, producing 125 horse power, and turning at a speed of 1850 revolutions per hour. This double turbine, though only 11 inches in diameter, propels a cotton mill of 10,000 spindles.

And now, gentlemen, to show what importance is attached in the practical applications of turbines, I have to say that the U. S. Centennial Exhibition has been engaged in preparing a most complete testing apparatus, where the world at large is invited to bring their wheels to be tested by a competent committee of mechanics. Let us hope that the results will establish the superiority of the turbines of the United States, in the ensuing competition.

plete both in leading plates and in the movable wheel, and the streams do not meet until their duty on the turbine is performed. The water thus gives its proportionate pressure on the wheel as it enters it and as it leaves it. It is hardly necessary to say that careful experiments have proved the advantage of this plan of turbines. The gate of the ordinary Jonval is generally placed at the outlet, where it is free from any injury, and to perform the duty of starting and stopping the wheel, no simpler and stronger arrangement could be desired, but for variable power or