for precipitating the soluble sulphates proceeding from the decomposition of pyrites.

The amalgamation of gold is favored by a temperature of 38 deg. to 45 deg. C., and still more by the employment of quicksilver in the nascent state. This last property is the base of the Designol process, which consists in treating auriferous or auro-argentiferous ores first ground with sea salt, in revolving cylinders of cast iron with iron and mercury bichloride, in such a way that the mercury precipitated collects the gold, and eventually the silver, more efficaciously.

[Concluded from SUPPLEMENT No. 1563, page 25042.]

SIMPLE STEAM TURBINE ENGINES—II. *

By JOHN RICHARDS.

It is not unusual, in papers of this kind, to introduce the subject of constructing and operating machines, and it might be out of place in papers relating to some kinds of machines employed in the arts; but, as before pointed out, information on this subject is, at this time, the lacking element in steam-turbine practice.

At the risk of prolixity I will summarize and restate in a compendious way the points already gone over, and then proceed to constructive features.

All fluid machines belong to two classes:

First, machines that receive and translate the force of fluids, or motive engines of all kinds. Second, machines to impel fluids, including pumps of all kinds. This is a division easily understood. Fluids include air, steam, water, gas, all of which come under and are amenable to certain ascertained laws, and are divided into elastic and inelastic fluids.

Fluid motive engines are divisible into two classes—positive and free running. The positive class includes all that operate with pistons and which measure, positively and in proportion to movement, the amount of fluid that passes through them. There is no time factor in positive-acting machines; hence the rate of movement and the work done in a given time are under control. Within certain limits a positive-acting machine may run fast or slow, and its speed can be varied at will. The latter is the most important advantage that positive or piston machines have over the impulsive or non-positive type, and lends itself to a wide field of uses.

This advantage of a variable rate of movement is, however, diminishing all the time, because of the improvement in transmission gearing, designed to change the relative rate of movement.

The free-running class of fluid machines, those which operate by impulse and reaction, have a "time function" to deal with, and their speed is a determinate quantity, based upon the flowing velocity of the impelling or impelled fluid. This class embraces water wheels of all kinds—gravity, impulsive, and reacting; also steam turbines.

The velocity of this impulse class of machines is inversely proportional to the density or weight of the fluids that impel them. A centrifugal pump and a rotary fan seem very different machines, but they operate according to the same law, and their speeds are inversely proportional to the weights of the fluids, or as 800 to 1. This indicates the great velocity at which single-action steam turbines must move, practically about 90,000 feet a minute.

Such a velocity produces various phenomena, such as the disturbance and stretching of the rotative parts by centrifugal strain; tendency to vibrate; noise, the heating and wear of journal bearings, and other things. The centrifugal strain can be imagined when we reflect that one pound of metal on the periphery of a wheel two feet in diameter, will, at a speed of 10,000 revolutions per minute, represent a centrifugal force of 34,000 pounds or 17 tons.

Referring now to the constructive features of steam turbines, the first thing considered will be the buckets, and at the beginning I will claim that these are at

but it produces, in turbine wheels, several features of construction that are far-reaching in effect, also far from apparent until carefully examined.

First. It increases the weight and number of buckets about fivefold in the attempt to secure impingement of the steam jets normal to the straight faces of the buckets.

Second. It distorts the course of reaction from a possible angle of 15 degrees to an angle of 20 to 30 degrees required to secure clearance.

Third. It makes necessary a side application of the jet, introducing lateral stress on the wheels and inducing vibration.

Fourth. It augments, in proportion to the added number of buckets, the amount of fluid friction; not to include the resistance of corners.

Fifth. The disposition of material in solid disks prevents the employment of its fibrous or laminated nature in the direction of strain and demands very expensive homogeneous material, a result indirectly of the numerous buckets.

This is a bold arraignment of certain constructive

FIG. 9.—FORM OF BUCKET ADAPTED TO A REDUCED NUMBER.

features, and would require great temerity on my part to bring forward were I not fortified by something stronger than inference and personal experience in this matter. I allude to the tangential water-wheel practice on this coast, which has passed through a crucial course of development that furnishes copious suggestion for single-action steam turbines.

The number of buckets is a very important matter. It is a sequence of the angle of impingement, and this again is a sequence of the bucket's shape, as will be shown further on. The surface or fluid friction, which offers a considerable resistance and loss, is in proportion to the number of buckets employed, and should be considered in this connection.

Most of the steam-turbine buckets now made have angular corners, and, when there are not such corners, the end walls of the buckets are so distant from the jet as to lose reactive effect in that direction. We long ago learned to keep water out of sharp corners in buckets.

In respect to the number of buckets or vanes, Fig. 5 shows how the line of impingement varies in respect to the straight faces of radial buckets, being as the sine of the angles *A* and *B*; and there is no way of securing impingement even approximately normal to the straight faces except by employing a large number of buckets set close together. The result is much the same whether the jets be applied on the side or tangentially, as shown in Fig. 6, where the angle of entrance is 20 deg. and that of discharge 36 deg.

The trend of practice in tangential water wheels has been to wider spaces between the buckets, better angles for discharge and recently to uniformly curved buckets, as hereinafter explained.

This feature of oblique impingement is accountable for at least three-fourths of the buckets now employed, and the result is loss by increased surface friction and distortion of the angle of reaction.

Fig. 6 shows approximately the entrance and discharge angles in the De Laval engines, embracing an arc of 56 deg., which, by reducing the number of buckets, could be reduced to 36 deg. or less if the problem of oblique impingement were out of the way. Fig. 7 shows spacing for tangential buckets to secure an easy discharge at 20 deg.

In the Riedler turbines, the angle of discharge is 180 deg. In other words, the discharge is opposite the jet, but this calls for increased surface, more width and weight for the revolving member, and expensive work in construction, which are hardly offset by countervailing advantages, and which certainly prevent a cheap and general manufacture of the machines. It would not be becoming in myself to criticize the computations and designs of Prof. Riedler, but I am looking at the practical and mechanical phases of the problem, and seeking means whereby such engines may be made at a reasonable cost by common facilities and operate at reasonable efficiency.

The contention is that the buckets of steam turbines should be curved in all planes approximately as shown in Fig. 8, taken from a form of water buckets of a very advanced type by W. A. Doble, of this city. These are of double concave or cup form, in order to permit direct and balanced impingement at the various angles in which they are presented to the jet, and have a central dividing wedge to permit tangential application. This latter is not presented as a new idea, being simply the final form and method for tangential water wheels on this coast, after more than twenty-five years of continuous experiment and the attainment of an efficiency that is, if not final, so nearly so that a very narrow margin of avoidable losses remains.

If there exists any reason why this same system or method of operating is not applicable to buckets for steam, I am not able to perceive it. Of course, expansion of the steam and divergence of the jets would

call for modification not determinable until a form of nozzle and the contour of the jet are assumed.

Not knowing how far the contour of a jet of steam will permit its passage through notch *A*, in Fig. 8, I am not able to say how far this feature is applicable to an elastic fluid, or how far such a passage as that at *A* would become a spillway when a jet was impinging at the opposite end of the bucket. I will not discuss this here, further than to point out that this passage *A* avoids passing the rim *B* of the bucket through the jet and the disturbance that must result from this cause.

The dividing wedge, *C*, permits tangential application of the fluid and produces a shallow and balanced discharge. As a feature of impulse-fluid motors, it has not met with analysis and adoption except on this coast and in the Riedler steam turbines. Its function, or rather its effect, is not always understood. The avoidance of side stress on wheels, especially on steam turbines at their enormous speed, is important, and so is the dual discharge which permits a more nearly uniform velocity throughout the discharged water section, because the latter is shallower. After many years of practical experiment, as well as some spent in scientific work, the dividing wedge was confirmed at the University of California in 1883* as a permanent feature of good practice for water.

In Fig. 9 is shown a form for buckets capable of receiving and properly reversing a jet of steam coming within angles *A* and *B*, and permitting the number of buckets to be reduced to what will come within and cover the divergence or expansion of the steam jet, or about one bucket for each 8 deg. of arc for wheels from 20 to 40 inches diameter. This is less than one-fifth the number now employed for wheels having buckets straight in one plane as in Fig. 6.

Such buckets can be stamped out of fine steel and made strong, smooth, and integral with their radial supporting stems. They can be made of uniform thickness, with no more metal than their operative functions require, and of less than half the weight of those cut from solid metal, so that, compared with the usual form of steam turbines, there would be one-fifth the number and (excluding the fastenings) less than one-half the weight, so that the mass in the rim of a turbine wheel with this form of buckets can be reduced to one-eighth or even one-tenth of that in common practice.

In the construction to be hereafter suggested, the buckets represent and constitute the whole rim of a wheel.

As to wheels or disks, nearly all now in use for single-action engines are solid disks, as shown in Fig. 10, a matter much to be wondered at if we consider the strains. Not everyone has had the opportunity of seeing disks at high revolution, circular saws, for example, which, at a speed of 10,000 feet per minute, assume a sinuous path at their peripheries and lose their stability by stretching.

A bucket, weighing an ounce, and revolving in a circle 24 inches in diameter at the rate of 10,000 revolutions per minute, will exert a centrifugal strain of one ton, and its supporting sector and fastenings will exert 50 per cent more—a result scarcely conceivable. The disposition of mass, strains and section may mathematically produce a body of the spindle form shown in Fig. 10 and in all diagrams that have been worked out by computation, but I do not believe that practical experiment will evolve anything of this kind.

Assuming this centrifugal force applied to a sector of a solid disk of uniform section, a circular-saw plate, for example, the error of such construction becomes apparent. The disposition of the material, in a sector of the wheel of which the bucket is the outer end, will be inverted, so to speak, and disposed inverse-

FIG. 7.

FIG. 8.—BUCKETS CURVED IN ALL PLANES.

ly as the strain. The perimeter has no function requiring a continuous mass there, unless it be to hold a series of buckets set close together or to provide mechanical fastenings for them.

To compensate this contradictory disposition of material, the wheels are commonly made in lenticular form, as shown in Fig. 10, so that the mass of a sector is approximately a radial body of nearly equal section,

* Partial Turbines or Tangential Water Wheels. College of Mechanics, Berkeley, Cal. By Ross E. Browne.

FIG. 6.—EFFECT OF NUMEROUS VANES.

fault in modern practice because of being curved in one plane only; consequently they have but one correct position in the jet throughout the whole arc of their movement and in nearly all cases are cut out of solid metal, and have angular or imperfect corners.

This form of buckets is due no doubt to the difficulty of machining their surfaces except in straight lines,

* Read before the Technical Society of the Pacific Coast.

apparently providing for centrifugal strain if change by elongation is ignored; but this latter is the principal fact and one which cannot be provided for in a solid disk of any form, because the conditions are not ascertainable. I have made diagrams to show the mass, in 10 deg. of arc, for several forms of wheels, but want of space prevents their reproduction here.

I have had made, by a very competent engineer, an analysis of the strains in several forms of solid disks, independent of elasticity and of change by stretching, a condition that defies computation in metal forms of the kind. It is an interesting, and also an intricate problem, but I believe of but little practical value.

A very extensive analysis of such disks or wheels, made by Frank Foster, was published in *The Engineer*, London, No. 2506, January 8, of the present year. It is a study in mathematics of a very abstruse and no doubt interesting nature to students in calculus, but the weight and cost of such disks, if there were no other reasons, preclude their use for plain simple engines, such as those to which these remarks are directed. Prof. Riedler seems to disregard such theories respecting the disposition of material in his disks.

I have shown how four-fifths or more of the weight in the periphery or rim of such wheels can be dispensed with, and I will suggest for the body of the wheels a construction which will eliminate inherent strains due to elongation or stretching, and at the same time dispense with the greater part of the mass and reduce the centrifugal strain accordingly.

In wheels moving at such high velocity, certainly the first thing should be to remove from the disruptive zone all joints and mechanical fastenings. These must necessarily include an extra mass of inert material at the points of juncture, plus bolts, rivets or other means of attachment. Buckets or other parts fastened by dovetail joints are open to the same objection, because extra substance must be added to endure compression and holding strain.

The construction shown in Figs. 11 and 12 is suggested, the buckets being made independent, avoiding circumferential strain and permitting free elongation by centrifugal stress. The spokes *B* are tapered, so that their sections will stand the centrifugal strain within the mass lying outside of any point. They are fastened in a nave by welding or by suitable mechanical means, the strength of which will equal their section.

The nave of the form shown in the diagram will not expand and become loose on a spindle with the amount of weight in a wheel constructed as shown.

In respect to gearing for transmission, I believe that the principal impediment is a want of confidence. Nowhere in the arts have we been called upon for translation at such high velocity; consequently we are not prepared to provide devices such as are required to reduce the speed of single-action steam turbines, where the elements of transmission have to move from 4,000 to 6,000 feet per minute. I know of no reason why plain tooth wheels, or tangent gearing, will not run at this speed, and I confidently expect that they will do so without any objectionable result.

Respecting tooth gearing there is much apprehension, which arises from the difficulties of constructing it in perfect form. In the Continental Hotel in Philadelphia a screw elevator was in use for more than twenty years. A bevel wheel of 5 feet diameter and a pinion of 10 inches diameter drove the screw, and they were absolutely noiseless. They were made at the Industrial Works in that city, where I was working at that time.

In an experiment made many years ago, at the works of William Sellers & Co., to test the ultimate speed of transmitting apparatus, bands of one kind or another were employed up to a point of failure, then plain spur wheels were resorted to, and, as I have been informed, they were entirely successful to the point of

and making machines in which the spindle bearings had a velocity of from 2,000 to 3,000 feet per minute, were subject to lateral strain and mounted in weak framing, and they ran cool when the fit and alignment were good. Consequently I am in no way alarmed at the requirements in steam-turbine practice, and I confidently expect to see power transmitted by bearings moving at a surface velocity of 5000 feet per minute and spindles run cool at 10,000 to 15,000 revolutions per minute.

In my opinion the gearing of transmission should be inclosed with the motor wheel, and should operate in the vapor contained in the casing, that being open to a condenser. There are three reasons for this: (1) The better performance and wear of wheels when steam lubricated; (2) the absorption of noise, if that be present; and (3) the avoidance of packing glands

FIG. 10.—SECTION OF WHEEL.

on the spindle of the motor wheel, a very objectionable feature, present, I believe, in all the steam turbines now made.

Such packing glands are objectionable not only because of a possible resistance and loss of power by friction, as pointed out by Prof. Sweet, but because they permit the entrance of air into the condenser and involve the wear and care of packing.

The interior of the wheel casing should be annular, turned smooth and otherwise so arranged as to permit the free revolution of any vapor it may contain. It has been suggested that a sector or spoke construction of the wheels would cause serious resistance by windage or fanning the steam or vapor in the casing; but the attenuated vapor in a casing, 10 to 12 pounds below the atmosphere, would not offer much resistance if fixed, and perhaps none to consider at all, if free to revolve with the wheel.

In respect to bearings for the wheel spindle, these should be parallel, hardened and ground, mounted in pivoted split shells of gray iron, and, like the reducing gearing, inclosed in and exposed to the vapor of the wheel chamber. This may seem objectionable because of heat, and it would be so in machines as now arranged, with the casing exposed to a high temperature.

This latter I believe to be a mistake. No avoidable heat should be communicated to the casing to raise its temperature above that of the expanded steam. A low temperature would not cause appreciable thermal loss in the jet, but would assist a condenser and conduce to other desirable objects that have been named.

In respect to nozzles for buckets, such as have been suggested, it is a difficult subject without experiment and when the contour of a jet at different pressures is not known. I am of the opinion, however, that if inclosed the tube should conform to the natural contour of the jet. With side application of the steam on

whom I have several times quoted, his opinion respecting steam-motor nozzles. He replied as follows:

"As regards the De Laval nozzles, the learned here are of various opinions as to their value. Prof. Meyer, in Zurich, who has experimented long with the De Laval, says that it is in no way superior to a common nozzle."

The views and suggestions which I have had the privilege of advancing here have been imperfectly embodied in an organized mechanism, shown in Fig. 13. This drawing was made about two years ago, and it would be modified in various ways if reproduced now. It, however, embodies most of the features that have been suggested.

I presume this presentation of a subject, without the scientific furtherance common at this day, can hardly be considered a conventional contribution to the art. It may not be so accepted, but I venture the prediction that the evolution of cheap steam turbines, adapted for general manufacture and use, will before long result from effort and experiment on the part of intelligent and experienced mechanics aided by scientific data.

This assumption has some answer in the fact that, already mentioned, seventy-five years ago Mr. Avery, a country millwright in western New York, made successful reaction steam turbines, and applied a large number of them successfully to common rough uses. He also made impelling members which contained about one-tenth of the material now employed, and, as I believe, in a more practical manner than in many wheels now being produced. The work was done in blacksmith shops, at a time when accurate tools and processes were almost unknown, and I am much inclined to agree with the opinions of Prof. John E. Sweet, whose skill and judgment no one is likely to question, who, in a recent letter to the author, said: "If I were to engage in the manufacture of steam turbines I would begin with the Avery one."

The steam-turbine practice of our day is the finest example of constructive engineering work that the world has ever seen. It is confined to large units, not because of operative impediments in small engines, but because these cannot be furnished separately at such prices as can be obtained.

From these premises I conclude that future steam turbines for common use will be single-acting and condensing whenever possible, with wheels of sector construction as light as can be made. There will be no packing glands on the main spindles, and the first movers for transmission will be plain spur or tangent gearing.

I will conclude this paper with brief mention of the economic results that have been reached with steam turbines, as illustrated by the generating engines recently constructed in Switzerland, one with very high-class piston engines and one with turbines, each of 5,000 horse-power. The results were as follows:

Weight of piston engines and generators, 598 tons. That of the turbines and generator only 78 tons, or nearly 8 to 1. The steam consumption by the piston engines was 11 pounds per indicated horse-power, and for the turbines 1 kilowatt with 14 pounds of steam, or about 10 pounds per horse-power. Oil consumption was as 20 to 1 in favor of the turbine, and attendance about 5 to 1.

The piston engines were made by Sulzer Bros., of Winterthur, and the turbines by Brown, Boveri & Co., of Baden, in Switzerland. The quantities were furnished to me by Mr. Brown, of Basel, Switzerland, with whom I had personally discussed the subject some time before the tests were made and who had forecast the result with much accuracy.

WOOD DISTILLATION.

Wood distillation has been tried in this country so extensively of late, and has been brought so promi-

FIGS. 11 AND 12.—TURBINES WITH REDUCED NUMBER OF BUCKETS.

FIG. 13.—THE COMPLETE MACHINE.

disrupting a steel disk driven by the gearing. Of course, such gearing to run without noise must be perfectly made; and, if there is reason why they will not transmit at 4,000 to 6,000 feet per minute, I fail to conceive it, especially when inclosed in the turbine wheel chamber, as hereafter suggested.

Twenty-five years ago I constructed machines in which bands of flax webbing ran at 6,000 feet per minute without difficulty.

These bands drove spindles at 12,000 feet per minute, and the machines are yet in use in Columbus, Ohio, where they were made in what might be called a country shop.

For a good many years I was engaged in designing

buckets flat or straight in one plane, there is no doubt a gain results from the use of a diverging nozzle, but in buckets in which the jet is divided the case is different.

On the whole, I think it safe to assume that the form of nozzles for steam turbines of the single-acting type is not a problem that will much interfere with their successful construction. That there should be a converging anterior chamber, a throat to determine volume and a diverging nozzle is obvious, but further than this the result is no doubt a refinement that has more importance in a mathematical theorem than in the workshop.

Some years ago, I think in 1901, I asked Mr. Brown,

nently to the attention of the Forest Service as a means of utilizing waste in lumbering, that a careful and thorough investigation is to be made by the service, covering both what has been accomplished in this industry and what may be done to reduce it to more scientific principles and to place it upon a sound commercial basis. The various processes now in use will be studied and compared, as well as the resulting products, and the uses to which they are or may be put.

To push this study to early and useful results with the least possible delay, Thomas W. Pritchard, a practical expert in wood distillation, has been engaged by the Forest Service to devote his entire time to the