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SPEED GOVERNMENT IN WATER-POWER PLANTS.

BY MARK A. REPLOGLE.

No problem in hydrodynamics has created so much interest in the past few years as the government of water-powers. When it had been demonstrated that power could be successfully transmitted to great distances by the use of electric currents, the economist very naturally conceived the idea of harnessing available waterfalls. It was well known that turbine water-wheels could be constructed that would furnish to a dynamo an efficiency of 75 per cent., or more, of the energy represented by the fall or head. The conservative engineer and the investor, however, were much concerned about the

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possibilities of regulation or government, and much diversity of opinion has been expressed by thoughtful and earnest engineers regarding it. Specialists have spent much labor in experimenting and developing apparatus to govern power plants. It has been demonstrated that water-power plants can be successfully governed. But the various degrees of regulation, ranging from indifferent speeds up to good engine practice, even with the same apparatus when used in different water-powers, prove that there are some underlying principles that must be adhered to if successful regulation is to be obtained by calculation or intelligent reasoning, and it is for the purpose of discussing some of these principles that this paper has been prepared.

Very little literature can be found that treats on the government of water-powers in a scientific manner, and what is extant shows that the German, Swiss and French engineers had spent much thought and labor on this subject years before the problem became an important one in America. Space forbids any comments on their experiments or practice, except to say that, until within a very few years, they were far in advance of our own hydraulic engineers in this particular part of power-plant construction.

Regarding the *early* work in this line, nothing better can be said than to quote the "Encyclopædia Britannica," which says: "The science of hydrodynamics was cultivated with less success among the ancients than any other branch of mechanical philosophy. If we except a few propositions on the pressure and equilibrium of liquids, hydrodynamics must be regarded as a modern science which owes its existence and improvement to those great men who adorned the seventeenth and eighteenth centuries." During the early part of the nineteenth century rapid advances were made by Europeans in methods of getting power from gravity by the use of the agent water. The interest awakened by the success attained, as well as the necessity of good government in localities where steam power was expensive, no doubt had much to do toward an early development of governing apparatus in the European countries. In America, steam-power has been so

cheap as almost to supersede water-power in some localities, and where steady power was a necessity it was almost invariably furnished by steam engines, water-power being used only where little or no government was required. Hence the American manufacturer was fairly satisfied with a device that would slowly move his wheel gates when too great a change was perceptible in the speed of his plant. Such device was called a governor until the electrical engineer of recent years discovered that his machinery was safer if he ignored entirely the so-called water-wheel governor.

The late successes in long-distance transmission make water-powers more valuable than they have been considered in the past, and the demands for reliable speed regulation are so urgent that there is a decided tendency on the part of engineers and investors to study the proposition more from a scientific point of view, laying bare, if possible, the principles that underlie it. These principles then may be used for foundations from which to reason out a solution of the problem. The doubts concerning the satisfactory government of water-power have often caused capital to be withheld where it otherwise might be earning handsome dividends. It is very apparent that speed government in water-powers should be reduced to an exact science, if possible, and it is hoped that this paper will exert some bearing to that end.

The following preliminary view of the proposition will disclose some of the difficulties that do not appear at first thought: First to be considered is the water. It is an inert material, incompressible, and having inertia, hence momentum when in motion. It contains no power whatever except that generated by gravity in giving it motion. Perhaps no better demonstration of the evil effects of inertia and momentum in governing can be given than the experience at the power plant of the Fresno transmission. (*Plate I.*)

A feeder pipe about 3,800 feet long is used to carry the water from *A*, the outlet of a reservoir on a mountain top, to *D*, the power house on the San Joaquin River. The fall or head in this case is 1,410 feet, and the pipe is amply heavy for all the ordinary strains that come in the manipulation of the

power. Before the plant was ready for actual operation, through some accident, a valve at *D* was opened, allowing a 4-inch stream of water to escape; the pressure gauge, which ordinarily showed 610 pounds to the square inch, dropped to 350. The valve at *D* was almost immediately closed by the attendant when the pressure-gauge pointer ran up to its limit, 1,000 pounds to the square inch. Immediately following this was a great writhing in the pipe line, ending in a report at *C* about 700 feet vertically above the power house. The pressure gauge dropped to about 300, and the flood of water coming down the mountain side indicated that the pipe had burst at *C*.

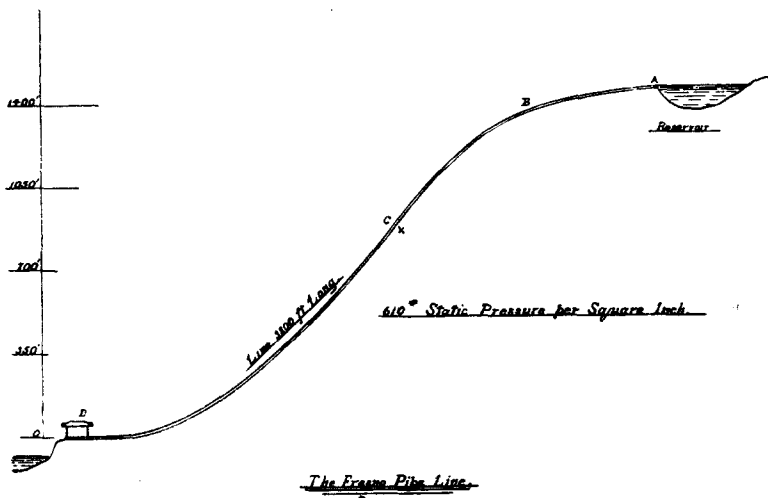


PLATE I.

Further investigation showed that the pipe from *A* to *B* had collapsed or flattened. The logical conclusion is, that when the valve was opened at *D* the portion of the water column from *B* to *D* began moving. That portion of the column from *A* to *B* lying in an almost horizontal plane did not have its inertia overcome quickly enough to follow, hence the column separated at *B*, causing a vacuum from *B* to *C*. When the valve at *D* was closed the water from *D* to *C* came to a standstill, raising the pressure by its momentum to 1,000 pounds per square inch, showing proof that the engineers had calculated correctly. By the time that the valve was closed at *D*

the column *A B* had been acted upon by gravity for some seconds, thereby giving it time to acquire considerable velocity, hence momentum; therefore, when it reached the other column at *C* the concussion burst the pipe, showing at one bold stroke the effect of incompressibility and momentum. The collapse in the pipe from *A* to *B* was due of course to the water emptying faster at *C* than it could enter at *A* (the pipe line here being of much lighter steel).

It can readily be seen that if government in this plant were attempted by changing the flow in the pipe line, as is ordinarily done, it would have been an impossibility if the safety of the installation was a consideration. Hence the governing is done by shifting a stream of water on or off the wheel as the power-demands require.

It might be added incidentally that the stream from a nozzle $1\frac{3}{8}$ inches in diameter furnishes about 500 horse-power, also that said stream can very quickly bore a hole through a granite rock or even a steel plate. It requires much care and ingenuity to handle this power plant, but it has been in actual operation for nearly two years, and is an unqualified success.

The inference to be drawn from the above experience is, that these evil effects appear in every power plant in a corresponding ratio to the length of pipes or closed flumes used to carry water to wheels. The injurious effect on government is to *change* momentarily the pressure or head on the wheel when any movement of the wheel gate is made. The effect is always the opposite from that required to keep even speed. Hence there is a limit to the time allowable in the gate movement.

The second factor to be considered is the water-wheel itself. It has a possible range of speed from zero to even faster than the spouting velocity due to the head, and it is unlike a steam engine in many respects. Its periphery must move at a velocity that is a proper ratio to the spouting velocity of the head, in order to gain the highest efficiency of power. The wheel also allows practically the same quantity of water to pass through it at any of its possible speeds. If any difference, it allows more water to pass through it at *under-speed* than it does at *overspeed*. So it can be readily seen *that*

an accurate gauging of the water that enters the wheel does not necessarily have anything to do with the speed. The speed of wheel is the result of quantity of water combined with pressure on one hand and load of work on the other. Therefore, any change in one of these three factors causes a change in the speed.

If a wheel at the end of a long-closed pipe containing hundreds of tons of water were running at normal speed, carrying a certain load, its speed would remain constant if no changes were made in the conditions. If, however, the gates were *slowly* opened, its speed would be increased by the greater quantity of water entering it. If, instead of this, a part of the load were dropped off, the speed in like manner would rise. If the gates were *slowly* closed the speed would soon begin to fall. But if the gates were *rapidly* closed the momentum of this column would cause a much greater pressure at the wheel-gate openings, and for an instant cause practically the same amount of water to enter the wheel at higher velocity. This amount of water having higher velocity will contain more energy or power for the time being, and of course will impart more to the wheel, increasing its speed slightly for a short time instead of immediately decreasing it, as would seem natural. This tendency for an increase in speed, added to the increase already caused by a part of the load being dropped, will make it necessary for a greater amount of work to be done by a governor than would be proper after the momentum effects in the pipe had subsided. It can also clearly be seen that, if the gates are opened again *quickly*, the velocity of the water entering the wheel will be decreased until the whole column acquires an increased motion; hence, the power applied will be diminished for a time instead of increased. These momentary and opposite effects make water government a harder problem to solve than the government of steam.

Third, water-wheel gates, as compared with steam valves, are heavy and unwieldy. They must also be moved through water, which is much denser than steam, hence cannot be moved with the same facility. They require much more power for *their movement*. Sometimes the designer of a water-power

plant does not place importance enough on the government of the wheels to make substantial gate rigging. The gate shafts may be too light, showing torsion when operating, or there may be a train of cog gears that allows much lost motion. The gates may be so designed that the water pressure gives them an unbalanced condition, requiring much pressure to be neutralized before it is possible to move them in a reliable manner. Turbine wheel gates built in this country often weigh several thousand pounds each, and sometimes must be moved several feet through water in being opened. Often it is necessary to add weight equal to their own weight as a counter-balance. The power required to overcome the inertia of and move this great mass often reaches many thousands of foot pounds. It can readily be seen that to govern such gates with precision and accuracy requires a combination of both delicate and powerful machinery. Also, when it is considered that it is possible to make the full change of an electric load in the fraction of a second and impossible for gravity to meet the power-demands short of a number of seconds, it is plain that to govern a water-power plant successfully is a matter of more moment than would seem at long range. It must also be borne in mind that the change of load must *occur*, and the speed must be *impaired* before it is possible for a governor to operate at all.

The fourth element to be considered is gravity, the source of all energy or power that can be had from water. Its effect can be considered as a constant in reasoning about power-getting. Of course, it is variable within certain limits. A square inch of opening at the bottom of a vertical column of water will allow gravity in a given time to generate a number of foot pounds of power, and in direct ratio to its height. This power is absorbed in giving velocity to a stream of water an inch square and spouting a number of feet per second. *Gravity has established an equilibrium in giving this velocity to the water.* If the opening were increased the power generated would increase in like ratio. It is the duty of the turbine wheel to reduce the velocity of this water as nearly as possible to zero without changing its own speed. In so doing the power is

transferred to the wheel shaft, where it can be carried to other points. With the exception of the small amount of power that is required to give a slow, downward movement to this vertical column of water, it can be said that the full effect of gravity is represented at the gate opening. Also, as soon as the opening is increased or diminished, there is practically the same increase or diminution in the amount of power represented by the volume and velocity of the water.

Again, if this column of water was extended in a horizontal direction from the top of the vertical column and the whole encased in a closed pipe or trunk, it can readily be seen that, when gravity operates on one square inch at the foot of the vertical column, it must put in motion the horizontal mass of water at the same time that it does the vertical mass. It is plain then that, while gravity has begun active operation as soon as the opening is made, its full effects will not be represented at the opening or wheel until the whole mass has been supplied with enough kinetic energy to give the necessary motion for the full spouting velocity at the gate opening. It is apparent that, while gravity is limited in the amount of power it can supply in a given time, it can be, and often is, further limited in its time of supplying power for governing purposes by the use of long pipes.

Considering the facts, that a change of load must be made before a governor can begin operating, that it requires time for a governor to perform its operation, that torsional and lost-motion effects are found in all gate riggings, that gravity must have time to do its work and may further be obstructed by injudicious flume construction, and that the wheel is limited to a certain opening and need not necessarily run in the ratio of the amount of water passing through it, it follows that absolute speed cannot be obtained in water-powers under heavy changes in load, as a change in load must necessarily change the speed before it is possible for gravity to furnish an increase in the supply of power. If there were no other factors government would be an impossibility, as a change of 50 per cent. in load would instantly cause a change of 50 per cent. in speed. But there *are* other factors, and, be it said to the credit of the

great engineers who designed America's greatest water-power plant, these other factors were clearly understood, intelligently calculated and incorporated into its construction. They are visibly stamped in every part of its make-up. (*Plate II.*) The first notable element is the size of the power units, 5,000 horse-power each. The second is the capacity of each unit for a storage of kinetic energy. It is absolutely necessary to have an accumulation of energy in reserve to tide over sudden fluctua-

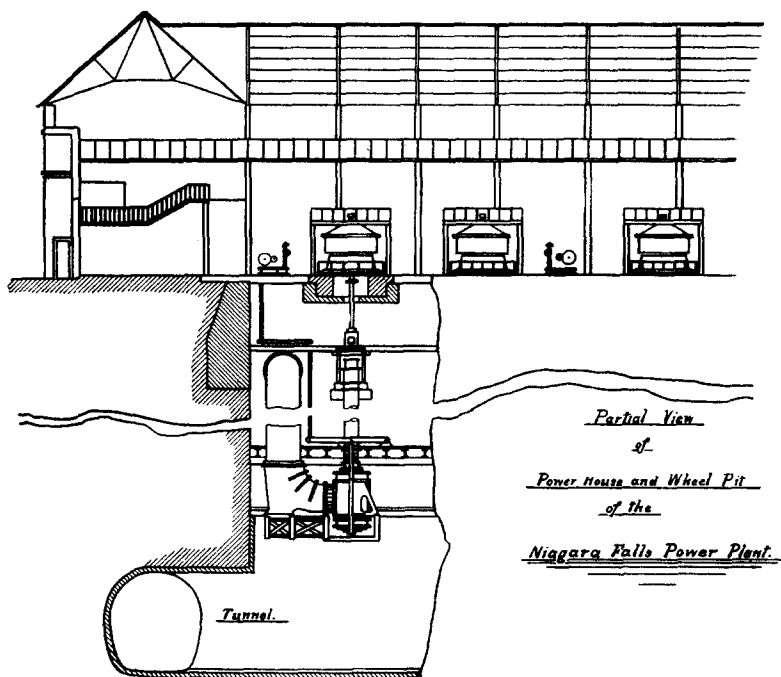


PLATE II.

tions in load until gravity can make proper compensation. The designers of the great Niagara plant first determined the degree of government necessary or desirable, and from this as a basis the plant was constructed. The results show that the speed government is well within the limits for which the units of power were designed. It is evident that there is a great accumulation of energy in reserve when an instantaneous change in load of 1,000 horse-power causes only 2 per cent. variation in speed, especially when the conditions are such

that it requires about three seconds of time for gravity to increase the power-supply to this amount.

There are several methods by which a reserve storage capacity can be maintained, but the one used at Niagara seems to be the simplest and most reliable. It certainly is the cheapest, being also purely mechanical. Reference is now being made to the balance-wheel or momentum effects of the revolving parts. It will be remembered that the armature, which is usually the lightest portion of a dynamo, is stationary in the Niagara Falls plant, while the field magnets, supported by an

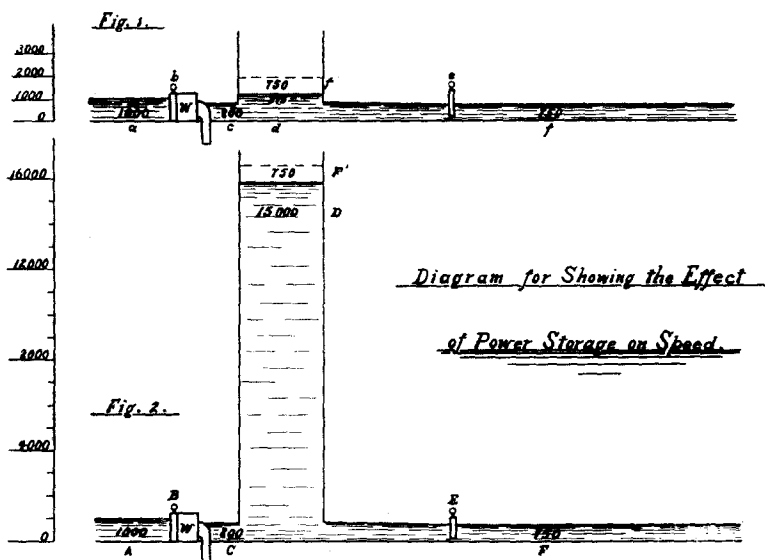


PLATE III.

immense steel band, are the moving parts. It is also noticeable that the great shafts reaching downward to the turbines are of large diameter, being great tubes. This is for the purpose of giving high velocity to as much of the material as possible. A certain capacity for stored energy was necessary for good government, and it is safe to say that if this could not have been reached with the present weights and velocities of parts, more would have been added in the form of actual balance wheels.

Plate III will serve to make clear the effects of power-storage in the government of a water-power unit.

In *Fig. 1* let *a* represent the power supply, *b* the water-wheel gate, *w* the wheel, *c* the turbine power, *d* the power storage, *e* the means of changing the load, and *f* the dynamos' power. It will be noticed that full 750 horse-power can be dropped off instantly by closing means *e*. The governor must operate at *b*, and it is safe to say that it cannot be in active operation before one second has elapsed. Note the condition at the end of the first second after the 750 horse-power was dropped. When *e* was closed there was only one outlet for the power generated at *w*, and that was to increase stored energy *d* to dotted line *f'* during the second. This increase will theoretically raise the speed of the whole plant 100 per cent. If it were not for some other principles that step in, this would be the actual speed at the end of the first second. In like manner, if the plant was running empty at normal speed, and 750 horse-power of load were added instantly, the plant would theoretically be standing still at the middle of the first second. Here also other principles step in and change this result somewhat.

In *Fig. 2* let *A* be the power-supply, *B* the water-wheel gate, *W* the wheel, *C* the turbine power, *D* the power storage, *E* the means of changing the load, and *F* the dynamos' power. Please note that all the conditions are the same, except that there is 15,000 horse-power of stored energy in *Fig. 2*, while there is only 375 horse-power in *Fig. 1*.

If *E* is closed, 750 horse-power will be dropped off, and finds a place at *F'*, increasing the volume of *D* 5 per cent., hence will theoretically increase the speed of power unit about $2\frac{1}{2}$ per cent. by the end of the first second. This is also lessened somewhat by the same principles that affect *Fig. 1*.

It can readily be seen that here is a means of preventing extreme changes in speed until gravity can perform its part of the work. Note the conditions in *Fig. 2* if running at speed and a load of 750 horse-power were added. If the load were suddenly added it must be carried from the reserve power at *D*, using 5 per cent. of it during the first second, hence reducing the speed about $2\frac{1}{2}$ per cent. theoretically. It can readily be seen that the speed will continue to drop until balanced

by new power generated at *W* after the governor has opened gate *B*. It can now easily be seen that *D* in any power plant can be increased until full change in load can be made with very narrow fluctuations in speed. In other words, every foot-pound of power or change in load can be intelligently provided for in the construction of a power plant, and variations in speed can be calculated for any change in load if the other conditions are known.

TABLE I.

POWER STORAGE OF SOME WELL-KNOWN PLANTS.

Name.	Units of H. P.	Power Storage Capacity in H. P. for 1 sec.	Ratio of Power to P. S.
Niagara Falls P. Co.	5,000	50,000	1 to 10
Sacramento L. & P. Co.	1,000	8,000	1 to 8
San Joaquin E. Co.	450	9,000	1 to 20
Portland G. E. Co.	600	3,000	1 to 5
Niagara Falls Paper Co.	1,200	400	1 to $\frac{1}{3}$

Table I will serve to give an idea how the power units of plants differ in the ratio of their power to their power-storage. It is safe to say that if the other conditions were equal the possible government in their speeds would show equally as great a difference. Space forbids any further comment, except that each plant is desirous of good government.

TABLE II.

APPROXIMATE LENGTH OF FEED PIPES IN EXISTING PLANTS.

Place.	Head.	Pipe.	
Ithaca	94'	600'	Ithaca Pipe
Great Falls	40'	400'	contains 737,500
Spokane	60'	600'	$MV^2 = 11,800,000$
Brantford	30'	210'	$= 338$ H. P.
Fresno	1410'	3800'	of kinetic energy in
Niagara Falls	145'	200'	in pipe.

Table II is intended to show the horizontal lengths of feeder pipes of some of the existing electric water-power plants.

It is unnecessary to go into the details of the calculations, but the purpose is to show the possible effects of momentum if the water-flow was stopped as quickly as an electric load is sometimes dropped. Taking the first in the list, that of the Ithaca Street Railway Company, it is found that the pipe holds 737,500 pounds of water. Assuming that this column

has a maximum velocity of 4 feet per second at full load, there will be a pressure of 11,800,000 pounds, or over 4,000 pounds per square inch at the water-wheel end of the pipe if the gates were closed as quickly as the load is dropped off. Since the static pressure is less than 50 pounds per square inch, and only a reasonable factor of safety provided, it is evident that a serious wreck would be the result of such a quick closing of gates. Yet such is necessary, theoretically, if even speed is desired.

It is also noticed that there is in this pipe before closing the gates 338 horse-power of kinetic energy for 1 second. Some disposition must be made of this energy, as it is necessary that the column of water be at rest when the wheel gates are closed. The only available disposition of it is to allow it to join the power set free when the load is dropped off, increasing its effect a like amount until the wheel gates can be safely closed.

It can now readily be seen that it is not only necessary to provide power-storage capacity enough in a power unit for the changes of load, but also an additional capacity for that contained in the pipes or flumes. This extra power must be provided on opening the gates before the wheel will furnish new power, and must be disposed of before the wheel will stop furnishing power when the gates are being closed. In other words, if the power unit in question is 900 horse-power, and calculations were being made to provide power storage so as to allow a full change of load to be made, keeping the speed inside of a given per cent., the calculations must be based on 900 horse-power plus 338 horse-power or 1,238 horse-power change at the whole gates. This makes it clear that closed pipes should be avoided as much as possible, if the government is to be done by changing the flow of the water. If it is desired to govern by deflecting the stream in some manner, the only detrimental effect of the long pipe is the power lost or gained by the varying friction in changes of load.

Plate IV is intended to show the conditions of speed on a 2,100 horse-power plant when 1,000 horse-power of load is instantly added. The kinetic energy in the pipe at full load is 1,000 horse-power for one second. The power storage of the

power new load for first second. While 200 horse-power has been added during the second second, it has performed an average of 100 horse-power work during this time. The power storage then has carried 900 horse-power of the new load during the second second. Since the full 200 horse-power is being added each second, the power storage is being gradually relieved of its drain and the speed stops dropping accordingly. A calculation at the end of each second shows exactly where the speed is at such time. Space will not admit the figures here, but the curve outlined by the crosses is approximately correct.

It is now evident that a formula can be deduced that can be relied upon in the government of water-powers. It will be somewhat complex on account of the many factors that must necessarily enter into it. Many of these factors will necessarily be fixed by the conditions that attend the plant construction. The size of the power unit will always be decided upon first. Next will be the maximum change in load, with the greatest variation in speed permissible. The time of change in power-supply is dependent upon the action of gravity and the safety of the plant. When the time required to supply power for the change of load has been learned, it is an easy matter to calculate the amount of stored energy or power storage that must exist in the plant in order to keep the variation of speed within the required limits. It will not be necessary to explain the fact that the speed will vary a fraction less in dropping off a load than it will in adding it.

In reducing the formula to its simplest form it will be necessary to combine or add together quantities that are of the same denominations, as follows: The time necessary to add power to overcome the increased friction in penstock, plus the time necessary to add power to overcome the inertia of the increased flow, plus the time necessary to add power for the new load, may be represented by T . The power necessary to equalize the increased friction, plus the power necessary to overcome the inertia in giving increased velocity to the supply, plus the power necessary to carry the increased load at speed, may be represented by L . The variation allowable in

speed in terms that are a fractional part of normal speed may be represented by F , and the power storage may be represented by S . Since the power storage must carry the new load for one-half of T , and since the speed of plant varies in one-half of the ratio that the stored energy is given out or absorbed, it is evident that the formula must read:

$$\frac{\frac{T}{2} L}{\frac{2}{2} F} = S$$

Further reduction makes it read:

$$\frac{T L}{4 F} = S$$

The following example will make its use understood:*

In the formula let T represent four seconds, L 1,500 horse-power, and F 3 per cent., or $\frac{3}{100}$ variation of speed allowable. In making substitution and reducing, the stored energy or power storage in the power unit must be 50,000 horse-power. This is the amount necessary if 1,500 horse-power is to be added, and it requires four seconds to get the proper effect from the power-supply, providing the variation in speed must not be over 3 per cent. from normal.

Before closing it will be necessary to make a few suggestions concerning governors. A properly-constructed governor must open the water-wheel gates as fast as gravity can follow up with water, no faster. It must close the gates slow enough to insure safety to the penstocks, no faster. It must be capable of stopping the gates at any degree of opening. It must be endowed with the relay principle, adjusted to co-

* In the formula $\frac{T L}{4 F} = S$

Let $T = 4$ seconds

$L = 1,500$ H. P.

$F = 3$ per cent. or $\frac{3}{100}$ variation in speed.

By substitution we have

$$\begin{aligned} 4 \times \frac{1500}{\frac{3}{100}} &= \frac{6000}{\frac{12}{100}} \\ &= 50,000 \text{ H. P.} = S. \end{aligned}$$

operate properly with the power storage. It must *not* be a separate and independent feature of the power plant, but must be made a part of the plant in an intelligent manner, and at best it is only one of the factors in the government of a water-power plant. It must be remembered that all the governor can do is to open or close the gates as the variations in speed require, and no water-wheel can be governed successfully by varying the gate-openings unless the same principles are adhered to that make government in steam engines a success.

The *relay* principle allows the governed motor to run at a slower speed when loaded than when running empty. This is for the purpose of using systematically the stored energy of the revolving parts of the power unit. Recently a new feature,

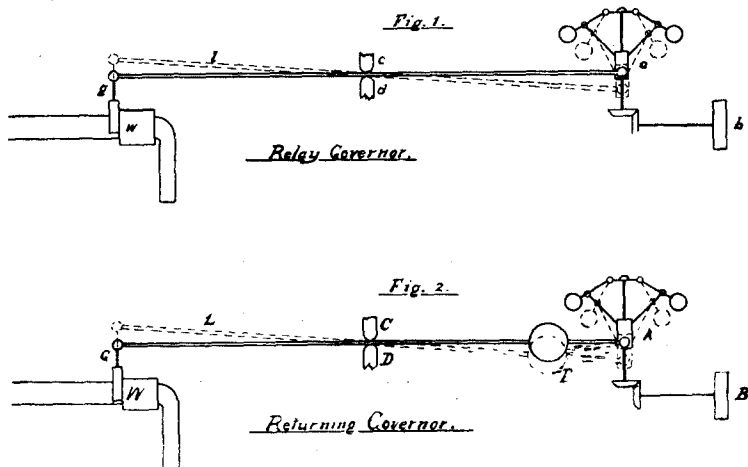


PLATE V.

generally known as the *returning* principle, has been added to some of the best-known governors. Both the *relay* and *returning* features will be shown in *Plate V*.

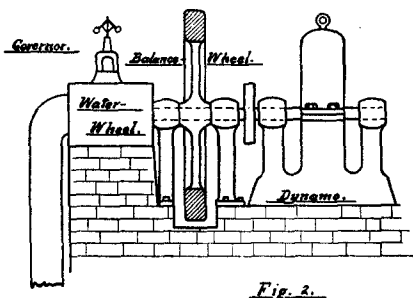
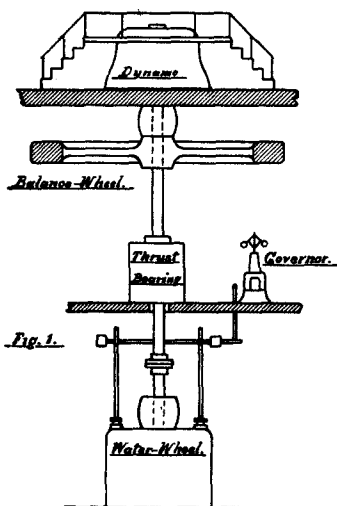
It is well understood that water-wheel gates are too ponderous to be moved directly by the centrifugal effect of governor pendulums. It is necessary to allow the speed governor to trip some heavier mechanical apparatus which moves the heavy gates. In some governors the pendulums throw into action an auxiliary power that in turn trips the apparatus that moves the gates. In *Fig. 1*, *a* is a speedy governor, *b* its pulley

that receives motive power from the water-wheel shaft, c is a trip to cause the heavy apparatus to close the gate, d is a trip to cause the mechanism to open the gate, w is the wheel, g is the wheel-gate, and l is a connection between gate and speed governor. (For the sake of convenience in the illustration l is a straight lever.) When the lever is so held by the governor balls that it touches neither c nor d , the gates do not move. If a change in load causes the speed to drop, the governor balls will allow l to touch d , and immediately cause the power mechanism to begin to open the gate. The gate in opening will raise l off of d , as is shown in dotted lines, causing the gate-moving apparatus to drop out of action. If this operation did not add new power enough to prevent the speed from a further drop, the same operation is repeated until the new power balances the demand and l touches neither c nor d . It will be noticed that the governor balls are running at a lower position after the gate has been moved to a wider opening. In practice this is a fact, and in this lowering of the speed a portion of the stored energy of the plant is fed out and used in carrying the new load, until the effects from the increased gate-opening can be had. If the power storage of the plant is proportioned properly to the change made in load, the speed can never fall out of the relay limits of the governor. But if the power storage is deficient, the speed on making a heavy change in load will quickly drop out of the relay limits, and the governor will then be at sea. The effect is called *hunting* or *racing* by engineers. (Let it be understood that an increase in speed will cause l to touch c , and close the gates in a similar manner.

Fig. 2 is similar to *Fig. 1*, with the exception that L is flexible or jointed at E . In a change of load L operates as a stiff lever, but after the equilibrium has been temporarily restored the lever L slowly begins to bend at E , allowing A to return to its original position. This bending or returning will cause L to touch D and add a little more water, until A has found its original position or speed, as is shown by dotted lines. It will be noticed that the power storage in *Fig. 2* is made use of in adding new load, by lowering the speed in the same man-

ner as in *Fig. 1*. But this defect is corrected later by the *returning* principle. The effect of the returning principle is to return the speed always to normal, leaving it identical with the speed at no load, a condition not ordinarily found in speed government where the relay governor is used.

Let it be understood that all steam engines that are successfully governed are controlled by the use of a relay governor, although it is not apparent to the casual observer. Some of our best steam engines use the returning principle in connection with their governing, although no reference is



General Design of Plant Constructions
that are Favorable to Government.

PLATE VI.

made to it in ordinary conversation concerning steam-engine government.

The science of water-power government has not yet reached so great a degree of perfection as the government of steam power, yet the underlying principles are being carefully studied by our engineers, and the time is not far distant when our water-powers will all be constructed and governed as reliably and successfully as our steam plants are, but that time will not come until the same principles are recognized in the former as in the latter. (*Plate VI.*)