closure under normal or abnormal velocity may be required. This valve is a recent development and has not yet come into general use.

In assembling the special fittings which connect the pipe-line with the wheels it is usually necessary to connect between two parts whose positions are fixed. In doing this it is of great importance that it shall be so done that no stresses will be thrown on the fittings by attempting to bring together surfaces which do not fit exactly. A much better way is to provide one piece in every assembly which can be fitted into place in the field.

Water-Wheels.—The water having been delivered to the power house under a head ranging from 250 to 2,000 ft., the next problem is to secure a water-wheel which will efficiently utilize the available energy. Two types of water-wheels are used: the Francis turbine for heads up to 700 ft., and the impulse water-wheel for any head up to 5,000 ft., a plant in Switzerland having a head of 5,412 ft. The suitability of either type for any given conditions of head, speed, and the horse-power depends upon the relation of certain functions of their physical proportions which are conveniently expressed as the "specific speed" of the wheel. This term is defined as the speed of a wheel, whose ratio of jet diameter to impulse-circle diameter, in the case of the impulse wheel, or whose ratio of runner opening to runner diameter, in the case of the Francis turbine, is the same as the wheel under consideration, but whose dimensions are such that it would develop 1 h.p. at 1-ft. head.

The formula for the speed of this assumed wheel is

$$Ns = \frac{Rpm \times Hp}{H5/4}$$

where Ns = specific speed
Rpm = revolutions per minute
Hp = horse-power delivered
H = head in feet.

Present practice indicates that the Francis turbines are suitable for heads as high as 700 ft. and specific speeds as low as 12 and that impulse-wheels may be operated on any head up to 3,000 ft. or over with specific speeds as high as 4 for heads up to 2,000 ft. There are so few plants employing heads above 2,000 ft. that practice has not shown just what specific speeds can be reached with impulse-wheels under these higher heads. Fig. 1 shows a graphical solution of the equation for specific speed for heads from 100 to 2,500 ft., speeds from 200 to 720 r.p.m., and from 1,000 to 25,000 h.p. An inspection of this diagram shows that there are many combinations of head, speed, and output which give specific speeds between 4 and 12 and which therefore cannot be met by either a Francis turbine or by a single-jet impulse-wheel. To secure a proper solution it becomes necessary to change the speed, or the output required from a single-jet wheel. In general, it may be said that the most desirable speeds for water-wheel generators from 3,000 to 15,000 kw. are in the neighborhood of 400 r.p.m., and that these speeds tend to call for impulse-wheels having high specific speeds and Francis turbines having low specific speeds.

From the standpoint of efficiency the water-wheel is by far the most important part of the plant since under favorable conditions a greater gain can be had in the efficiency of the wheel than in any other part. It is therefore essential that the speed and output of the units be selected with reference to securing the best possible conditions for the water-wheels. Minimizing leakage and taking care of end-thrust are problems of great importance in the design of Francis turbines. Present practice gives a satisfactory solution for both these problems. Balancing is accomplished automatically by the proper arrangement of the leakage ports.

The attachment of the bucket to the wheel-centre and the shaping of the bucket so as to avoid interference with the jet are most important in impulse-wheel design. At 1,000-ft. head the impact of the jet on the bucket is 21,650 lb. for 10,000-h.p. output. The stresses on the bolts holding the bucket to the wheel are therefore high and change very rapidly as the bucket passes under the action of the jet. The best forms of attachment thus far developed are (1) "chain bolting" using a double wheel-centre and a bolt which passes through the lugs of two adjacent buckets, or (2) the "two-bolt" or "three-bolt" arrangement which employs a single disc with buckets having two lugs straddling the disc and extending for some distance toward the wheel centre. Two or three bolts, preferably tapered, are passed through the lugs and the wheel-centre.

Control.—The only method of governing the Francis turbine consists in varying the positions of the wicket-gates which changes the amount of water supplied. For heads above 250 ft., and particularly where the pipe-lines are long, some form of pressure regulator must be provided to lessen the rate at which the flow of water in the pipe-lines is reduced, when the load is suddenly decreased. Practice indicates that the Escher-Wyss type of pressure regulator, which is essentially an inverted needle-valve, is most satisfactory. This pressure regulator automatically opens when the turbine closes and closes at a rate sufficiently slow to prevent shock. If the load fluctuations are severe the regulator can be set so as to operate synchronously with the turbine and maintain a constant flow in the pipe. The relief valve is not a limiting feature in designing Francis turbines for higher heads since they are used on heads as high as 2,000 ft. in connection with other types of wheels.

Two general methods have been developed for governing impulse-wheels. A deflecting nozzle is used in which the jet is deflected from the wheel when the load decreases, and restored when the load returns. In combination with a needle-valve, by which the output of the jet may be varied at a rate sufficiently low to prevent shock, the deflecting nozzle is a very simple, safe, and satisfactory means of governing. A modification of this method consists in using a "cut-off hood" to deflect the jet from the wheel. This plan is suitable for small wheels and low heads, especially where a simple arrangement is desired. To minimize the loss of water, direct governing of the position of the needle-valve is used with some form of relief valve to reduce the shock on the pipe-line. The best form of control will depend upon local conditions. No one form will meet all requirements.

Generators.—The generators in the high-head plant are of interest in that they have to meet conditions somewhat different from those of any other plant. Experience confirms the theoretical necessity for a rotor which will be safe at the maximum runaway speed which may be attained by the water-wheel. In the case of the impulse-wheel the runaway speed approaches 100% overspeed, and the Francis turbine of low specific speed may reach nearly 75% overspeed. It is therefore considered necessary to have the rotor so designed that no part will be stressed beyond the elastic limit at 100% overspeed. The speeds most favorable for the high-head water-wheels are of an order which gives a well-proportioned generator when the rotor is designed to be safe at 100% overspeed. In other words, the rotor will be from 9 to 10 ft. in diameter at 400 revolutions per minute.