velocities permit of a design of bucket to handle large quantities of water. In such a runner, thin warped buckets of ample size and large openings can be used. These buckets are, relatively speaking, structurally weak. High heads and consequent high velocities make necessary a simple design of bucket, thicker material, and, therefore, relatively small quantities of water. Strength, therefore, must be carefully considered in determining the diameter and speed of a runner. In general it may be said that for proper strength and design, the following specific speeds may be used for any head below the maximum head given.

Specific Speed. K rev. per min.	Maximum Head. feet.	meters.
68 to 75	50	15
50 to 68	100	30
35 to 50	200	61
25 to 35	400	122
10 to 25	600	183

This tabulation is not by any means fixed and is merely given as a guide. If the specific speed figures out for any given head as greater than the values given above, two runners should be used. If two runners are used, the specific speed must again be figured out with a horse power one-half of that used before. If head were the only determining factor, the specific speed could be chosen from the above table and the rev. per min. calculated from the formula.

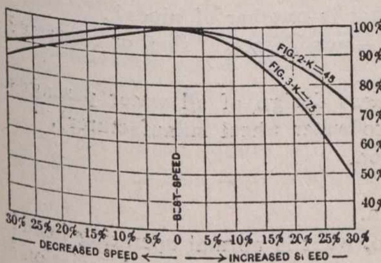

Fig. 9.—Effect on Power of Change of Speed, Based on Constant Head.

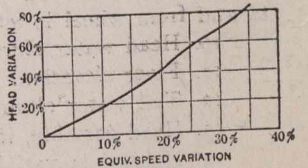

Fig. 10.
(See Fig. 9.)

(b) Characteristic Efficiency.—It has already been shown that different values of K result in a different efficiency characteristic. From our formula it is noted that specific speed varies with rev. per min., hence for any given horse power and head the rev. per min. fixes the specific speed, and the efficiency which is obtained from a runner with this specific speed both for full load and for partial loads. The particular speed characteristic desired, therefore, has much to do with selection of the speed of the runner.

(c) Balancing.—A single runner can be designed so as to balance thrust. This is sometimes desirable. With a single runner we have a lower specific speed and, therefore, consequent large diameter of runner. This should be considered by the designer and used where possible. The question of thrust does not enter into consideration with a pair of runners, as these are placed on a shaft as right and left-hand runners and the thrust of one runner is neutralized by that of the other. It is often found, however, that when a pair of runners is used, other conditions of the design must suffer and perhaps to the disadvantage of the installation. In making a proper selection of speed, therefore, the question of balancing is of importance.

(d) Speed Regulation.—Speed regulation is oftentimes the most important item in fixing the speed. The lower the speed the larger are the diameters and weights of the rotating element and, therefore, the greater flywheel effect of the unit. When the load on the unit is changed the speed varies directly with the flywheel effect. It is therefore often desirable to use a lower speed, fixing this speed by the degree of regulation desired. Extra flywheel effect can be obtained by the use of a flywheel, but this is generally undesirable and if possible should not be considered on account of the danger due to high pressures on bearings, etc.

(e) Variation in Head.—This is a common condition in low head plants. In hydroelectric plants the speed must be kept constant, even though the head does vary. In the case of pulp grinding mills, speed variation is not of so great importance.

We have already shown in Figs. 8 and 9 that different speeds have different characteristics of power and efficiency when the runners operate under heads other than the heads they were designed for, and lower speed than that given in some manufacturers' standard table of speed may oftentimes be used to advantage and might mean a considerable increase in the output of the plant. At the same time the initial cost may be greater and in such cases a proper balance between cost and benefits must be found.

To get a full conception of the effect of variable speed let us take an example:

Example.—A certain water plant has installed in it a water wheel runner of type No. 3, K = 75, which is designed to deliver 1,000 h.p. maximum at 200 rev. per min. when operating at 40-ft. (12 m.) head. This particular plant is so located, however, that the head varies due to floods, and at times the operating head drops down from 40 to 24 ft. (7 m.) The plant is a hydroelectric plant, and the generators driven by the water wheels require a constant speed of 200 rev. per min. in order to operate properly on the electric system connected to them. Let us investigate what will happen under these conditions. One of our fundamental formulas states that the horse power varies as $H^{3/2}$. Therefore, at 24-ft. (7-m.) head our 1,000-h.p. wheel will give

$$\frac{1{,}000}{\left(\frac{40}{24}\right)^{3/2}} = 465 \text{ h.p.}$$

This calculation, however, is based on the assumption that we allow the wheel to run at the proper speed for 24-ft. (7-m.) head, which speed would be in accordance with the formula: rev. per min. $\propto H^{1/2}$. Thus,

$$\frac{200}{\left(\frac{40}{24}\right)^{1/2}} = 155 \text{ rev. per min.}$$

Now, as a matter of fact, we do not want to allow this change in speed for the reason stated above, and as this is the case, we must sacrifice some of our power. If, therefore, we decrease the head from 40 to 24 ft. (12 m. to 7 m.) which is a drop in head of 16 ft. (5 m.) or a change of 40 per cent. in head, we will have, in accordance with the chart in Fig. 10, a corresponding speed variation of approximately 20 per cent

Referring now to Fig. 9 we note that for an increase of 20 per cent. in speed, there is a corresponding decrease in power for a Type 3 runner of 25 per cent. We would sacrifice, therefore, when operating at these changed conditions, 25 per cent. of the power which the runner operating at its best speed for this head possesses, that is, 25 per cent. of 465 h.p. or 115 h.p. We would have left, therefore, when operating the wheel under these changed conditions as brought about by flood, the difference between 465 h.p. and 115 h.p., or 350 h.p. If a runner of type No. 2 K = 45, should be installed in this plant instead of a runner of Type No. 3, it is readily seen from Fig. 9 that when operating under the changed conditions brought about by the flood, the loss in power, instead of being 25 per cent., would be but 12 per cent., which is a loss of 57.5 h.p. The power,