SPEED VARIATION BY A GRAPHICAL METHOD

PERCENTAGE SPEED VARIATION FOR DIFFERENT GOVERNOR TIMES AND VARYING AMOUNTS OF LOAD CHANGES IN A HYDRO-ELECTRIC POWER PLANT, INDICATED GRAPHICALLY.

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THE problem of finding the percentage speed variation for different times of governor, and varying amounts of load change, is one with which the hydro-electric engineer has often to deal. The number of variables is such that it is difficult to grasp the range and variations unless resort is had to graphical means. The writer has recently had occasion to use such a method, which may be of interest to engineers dealing with like problems.

The methods used in modern hydro-electric plants to preserve uniform speed under various conditions of service are too well-known to warrant full discussion, but it will be necessary to give a brief résumé of the factors influencing speed-regulation in order that the chart illustrated may be understood.

With high head plants, speed regulation becomes increasingly difficult, on account of the increase in the length of the feeder pipe lines, and the necessity for the economical use of the small amounts of water often conserved in costly storage reservoirs.

The amount of energy stored in the moving water of these pipe lines precludes rapid speed regulation, unless other means are used to furnish deficient energy when load is thrown on, while the water is speeding up in the conduit to the new required velocity; and conversely, when load is thrown off, to take up the excess of energy which must be dissipated gradually.

While this adjustment of velocity of flow is being made, the increase or decrease of energy is usually taken up by one or more of the following remedies, *viz.*, synchronous by-pass, deflecting nozzle, flywheel, relief valve, breakplates, governor-actuated pressure regulator or surge tank.

Where the first methods are used, in case of load thrown off, the water is by-passed by means of a valve operating by pressure directly connected to the water-wheel gates and arranged to open as they close; when load is thrown on, dependence is placed on the extra flywheel attached to the wheel to give the additional amount of energy required. Modifications of this may be used, such as a by-pass indirectly controlled by the movement of the governor so that any movement of the governor actuates a relief valve. With load thrown on, however, a limit quickly comes to the available speed regulation on account of the flywheel required. It is to this aspect of the problem that the chart and discussion applies. The method used for the analysis of the problem is that given by Mr. W. Uhl in his paper published in the February, 1911, Journal of the American Society of Mechanical Engineers. The graphical treatment is based on methods illustrated in Peddle's treatise on "Construction of Graphical Charts."

In an open-flume turbine setting, the speed regulation is dependent upon the flywheel effect of the connected rotating masses; the variation being in accordance with the following formula: $s_1 = \dfrac{800{,}000 \times H.P. \times T}{n^2 \times (w\,e^2)}$, where s_1 equals the speed variation or ratio between total speed change and normal speed; $H.P.$ represents horse-power load variation; T the regulating time; $(w\,e^2)$ the moment of inertia of rotating masses, and n the normal revolutions per minute.

The value of s_1 must be modified, due to several causes; the friction load of the generator and turbine remains and will tend to reduce the speed variation. Also, providing the turbine is correctly designed so as to give its maximum efficiency at normal or synchronous speed, the efficiency will be reduced with either increasing or decreasing speed. The amount reduced varies with the type of runner, being greatest for a high-speed, high-power runner, and least for a low-speed, low-power runner, since if correctly designed, the change in efficiency will be greater for a high-speed than for a low-speed runner for the same per cent. of variation in speed. The new value of s_1 to be used we will call s_2, and $s_2 = c\,s_1$ where c is a constant, as follows:

Type of runner (Specific speed)	13.55	20.3	29.4	40.7	$\frac{49.7}{62.8}$	$\frac{70.97}{83.78}$
C	.714	.703	.69	.671	.645	.606

Regarding the value of T in the above. The governor manufacturer will state the time required for a complete stroke of the governor, and experience shows that the time required for a governor to alter the power of a water-wheel after a great or small sudden load change will be approximately constant and equal to the time required for a full stroke or T.

As noted previously, a large amount of energy is stored in the moving column of water when long penstocks are used. Changes in velocity, therefore, involve changes in the kinetic energy, and produce pressure variations or oscillatory waves in the conveying conduits. It is this pressure variation or water hammer which develops when the flow in a pipe line is disturbed by the movement of a gate located either at the upper or lower end or in an intermediate position. These waves or oscillations once set up, continue until they are smothered by the friction on the walls of the pipe and between the molecules of water.

The velocity at which these waves travel is of considerable interest as on this depends the time element of the disturbances. This velocity depends upon the compressibility of the water and upon the nature of the material of which the penstock consists. It is found to vary from 1,000 feet a second for large diameter pipes to 4,500 feet per second for small diameter, and may be figured for any given set of conditions. Knowing this velocity, a, the minimum regulating time of the governor must always be greater than $\dfrac{2L}{a}$ where L = length of the penstock, otherwise dangerous interference to regulation, due to speed oscillations, will be developed and extreme pressure heads will exist on the valves and penstocks.