Simple Basis for Securing

Efficient Hydro Operation

Determination of characteristics of unit performance is
necessary in order to make fullest use of available water.
Calculation of operating curve does not require complete
test of unit, but may be based on the index of one factor

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AS THE water resources of the country become
more and more developed and greater numbers
of hydro-electric plants operate on controlled
storage it becomes increasingly important in the utiliza-
tion of investment that every one of these plants shall
work as closely as possible to its best point of efficiency.
Departures from this point, except in times of excess
water for which no storage is provided, mean actual
losses of kilowatt-hours that could have been saved. The
quantity of energy lost by inefficient operation may be
difficult of exact evaluation, but the loss does exist, and
the fact that it is indeterminate should not prevent the
effort to save it from being made. To get the most out
of a hydro unit a definite operating curve is required.
Such a curve is usually considered to be capable of
calculation only after extensive tests. Such is not the
case, as it is not necessary to make an exhaustive check
on a unit in order to erect its operating curve. The
curve may be set up on the index furnished by a single
and easily secured factor of operation.

In a way all hydro tests are index tests, in that errors
or slightly indefinite coefficients such as angular char-
acteristics of current meters, pitot tube coefficients or
weir constants are a constant bar to absolute water meas-
urement. The index methods here described simply
allow wider latitude in that respect, but in so doing
detract in no way from the utility of the resulting oper-
ating curve for use in enabling the development of the
most kilowatt-hours from available flow. Condition of
units may be checked periodically by these methods, but
determinations of quantity of water used, absolute effi-
ciencies and comparative performances in respect to
other plants may not. The essential features to be
watched in making an index test are gate setting, dis-
tribution of flow to adjacent units, condition of racks
and the use of a single means of measuring output.
Gates should always be set by an indicator having the
least possible lost motion and always be set in a direc-
tion opposite to their drift tendencies.

In this article are given typical examples of operating
curves erected on velocity gage, current meter and im-
pact gage tests, together with the mathematics of each
case. Whatever manner of test is employed the deter-
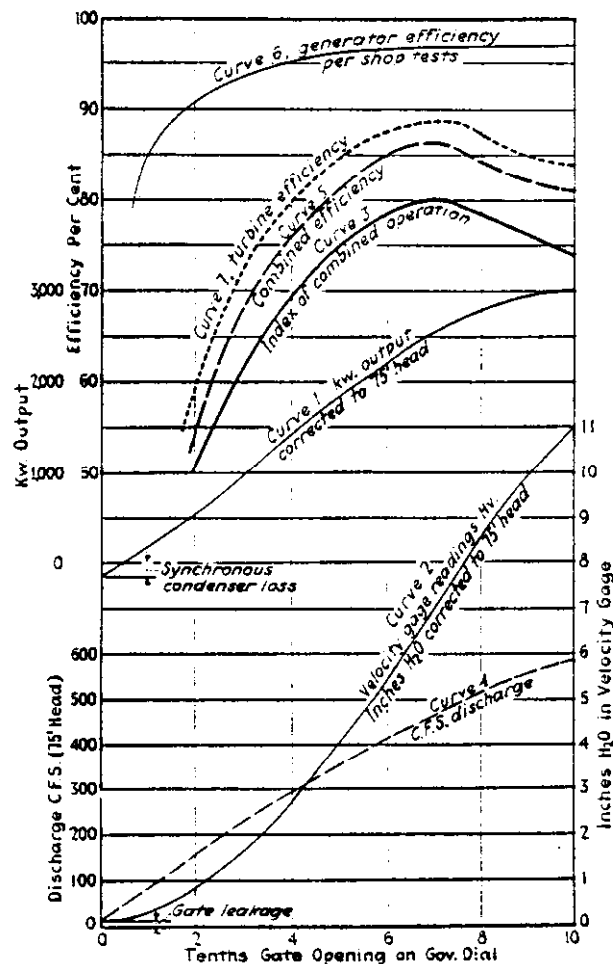mination of the curve is based upon the same condition.

*Fig. 1—Operating Curve Developed
from Velocity Gage Index*

This is that the break in the energy output curve of
the unit occurs at a gate opening that is at or very close
to the most efficient operating point. The other points
on the curve are determined in their relations to this
one, not necessarily in terms of any test or operating
quantities, but only in those relations. That is to say,

the best point at which to operate a unit is at its highest efficiency, but it makes no difference what this point is; the object is merely to establish the curve in relation to it. The break in the output curve is that point where it begins to flatten out, where increases in the gate opening add markedly less to the power output. If the curve has a well-defined "knee" the break is easily and definitely located; if the curve is so smooth as to make the break difficult of exact location the need of its exact location is less important and its reasonable approximation will suffice.

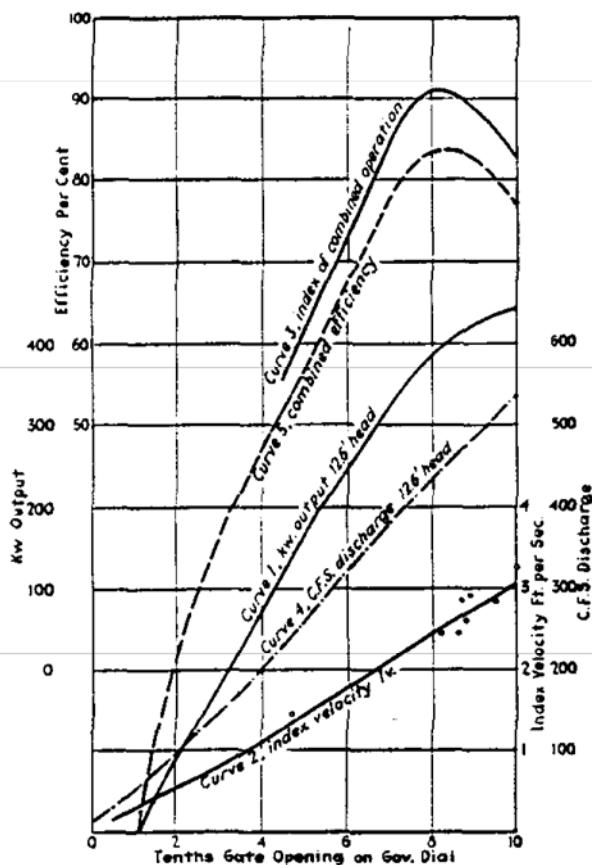Taken with the foregoing comments, the following examples of typical index test observations, their computations, efficiency assumptions and determinations of operating or index curves should illustrate the limitations and value of this type of test. It should be remembered that for operating purposes the performance curve may be plotted as efficiency, either high or low, or merely as a meaningless number like kw. divided by square root of impact, without detracting from the value of the resulting curve.

Fig. 2—Operating Curve Developed from Current Meter Index

VELOCITY GAGE INDEX

The application of a straight velocity gage to the determination of the operating curve of a unit is illustrated in Fig. 1. The plant in question had a single unit of 3,750 hp. at 75-ft. head developed through about 500 ft. of 11-ft. diameter penstock. Two velocity gages were available, one including pipe friction and the other only inlet and rack losses and inlet velocity head. The latter was used. It consisted of two glass tubes connected respectively to the pond and to a flush opening in the penstock about 50 ft. downstream from the racks. The upper ends of each were open to atmosphere and brought adjacent to a common scale on which the difference H_v was measured. In this type of gage the utmost care is required to keep pipes to the gages free of air. Any connection that will give a readable displacement is satisfactory, whether it arises from friction, velocity or impact. *Readable indications may be obtained from low or high pressure effects by using a differential gage based on liquids of densities greater or less than water.* The following are commonly available:

Liquid	Approximate Specific Gravity	Liquid	Approximate Specific Gravity
Gasoline*	0.7	Carbon tetrachloride (carbona)*	1.54
Kerosene*	0.8	Carbon di sulphide	1.25
Water	1.0	Bromoform	2.9
Carbon tetrachloride and gasoline*	0.7 to 1.5	Mercury	13.0

*Will retain color in presence of water if tinted with iodine or some of the aniline dyes.

The data of curves 1 and 2 in Fig. 1 are easily *obtained on commercial load and to take them requires only an hour or two for all gates.* From this data curve 3 is computed and such a curve is all that is needed for plant operation. The data appear in Table I.

Assuming 80 per cent maximum efficiency (90 or 100 or 60 could be assumed with equal utility) at the "break" of the kilowatt curve, where the best efficiency of a turbine usually occurs and which by inspection is at about 0.7 gate, and as the head in the velocity gage is caused by velocity head and friction head we may fairly assume that it is a function of V^2 and we may write:

$$H_v = C \frac{V^2}{2g}$$

or
$$V = C_1\sqrt{2gH_v}$$
whence
$$Q = AV = AC_1\sqrt{2gH_v}$$

For 11-ft. diameter pipe and expressing H_v in feet in place of the observed inches of water this becomes:

$$Q = 95C_1\sqrt{\frac{2gH_v}{12}} = 220C_1\sqrt{H_v}$$

Combined efficiency $= \dfrac{kw. \times 1.34 \times 550}{Q \times H \times 62.4}$ which, for 75-ft. head and substituting for Q its value as H_v, becomes

Combined efficiency $= \dfrac{kw.}{C_1\sqrt{H_v} \times 1.397}$ or $\dfrac{kw.}{C_2\sqrt{H_v}}$

Table I—Efficiency from Velocity Gage Index

	1	2	2a	3
			Combined Efficiency—	
				Figured (Curve 3)
Tenths Gate	Kw. Output	H_v Inches	H_v Assumed	Per Cent
10	3,000	11.0	3.32	...	74.0
9	2,920	9.9	3.14	...	76.2
8	2,800	8.6	2.94	...	78.3
7	2,600	7.1	2.66	0.80	80.0
6	2,220	5.5	2.34	...	75.0
5	1,850	4.1	2.03	...	75.3
4	1,450	2.8	1.67	...	70.0
3	960	1.6	1.26	...	62.2
2	550	0.8	0.89	...	50.4
1	200	0.25	0.50	...	33.0
0	-150			Synchronous condenser operation.	

Now using an assumed 80 per cent efficiency as the test point:

$$0.80 = \frac{kw.}{C_2\sqrt{H_v}}$$

$$C_2 = \frac{kw.}{0.80\sqrt{H_v}}$$ and using values for 0.7 gate

$$C_2 = \frac{2,600}{0.80\sqrt{7.1}} = 1,220 \text{ approximately.}$$

from which the efficiency for all gates may be figured

$$\text{Combined efficiency} = \frac{kw.}{1,220\sqrt{H_v}}$$

giving column 3 in Table I. Incidentally, a curve of kw. divided by $\sqrt{H_v}$ would be as useful for operation, but it is ordinarily desirable to have the curves approximate fairly closely to the absolute efficiency values, which in familiar form peak between 80 per cent and 90 per cent for combined units.

This particular plant was carefully tested by *Professor Allen*, using the salt titration method. The results are shown in curves 4 and 5. These, of course, give absolute efficiency within the margin of test error and as such make the plant valuable as a check on river flow and to determine whether the units meet the efficiency guarantees. They do not aid in operation otherwise. The turbine efficiency curve 7 is simply deduced from curves 5 and 6.

These curves of Fig. 1 are representative of the velocity gage type of results. I. A. Winter of the Alabama Power Company has carried this principle one step further by using the variation of pressure from the outside to the inside of a spiral casing near the guide vanes for a source of H_v. This is calibrated by a complete test and a permanent recording meter installed after that calibration to show continuous discharge figures. Caution is required, in that connection, not to locate the inner orifice so near the guide vanes as to run into interference that would modify the character of flow past it. E. A. Dow of the New England Power Construction Company has regularly made use of velocity changes in butterfly valves for the same purpose, such a valve acting exactly like a venturi meter up to the limits of its velocity difference.

CURRENT METER INDEX

Exactly comparable results may be obtained in open flume settings by using a current meter or several of them. An index point or a series of them are definitely located and the meter or meters read for five to ten minutes continuously to eliminate pulsating flow effects. An index reading is thus obtained that is directly proportional to turbine discharge in place of the square root function of the velocity gage. The sketch (Fig. 3), shows a typical power house arrangement in which this form of gage or index test may be used.

Two current meters were fixed at stations 4 and 11 at elevation 5. Adjacent units were operated at fixed gate positions throughout the index tests and the racks were kept clean. These precautions are of utmost importance. The data obtained are shown in Table II.

With gate openings, kilowatt loads and velocity indices available the procedure was as follows: From the shape of the kilowatt curves in Fig. 2 seven-tenths gate was assumed to be the best point. Any other gate opening
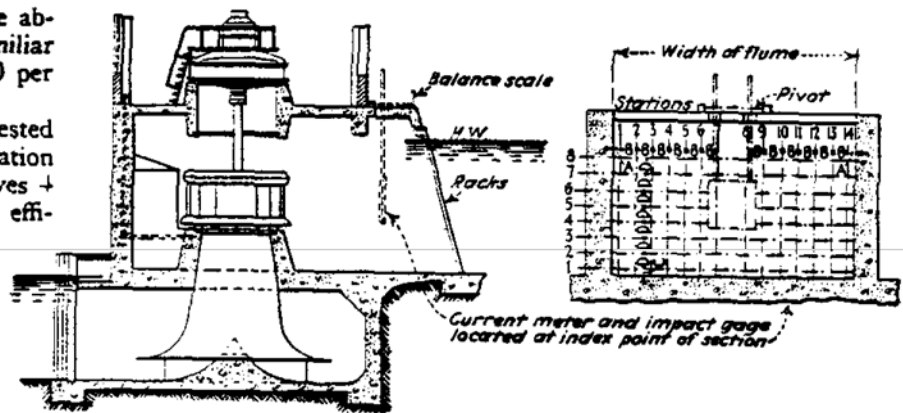

Fig. 3—Cross-Section of Unit Showing Locations of Current Meters and Impact Gage

might equally well have been taken without any change in shape of curve resulting.

$$\text{Combined efficiency} = \frac{kw. \times 1.34 \times 550}{Q \times H \times 62.4}$$

but $$Q = CI_v \text{ and } H = 12.6 \text{ ft.}$$

So combined

$$\text{efficiency} = \frac{kw. \times 1.34 \times 550}{CI_v \times 12.6 \times 62.4} = \frac{KW}{I_v C_2} = 0.85$$

Whence $$C_2 = \frac{kw.}{I_v \times 0.85} = \frac{320}{2.15 \times 0.85} = 175$$

Applying this to the observed index and kilowatt readings column 3 is obtained. This plots as in curve 3 from the relationship:

$$\text{Combined efficiency} = \frac{kw.}{I_v 175}$$

The assumption of 85 per cent at 0.7 gate was in error as subsequent test indicated in curve 5. but our curve 3 is as reliable a basis for operating the unit at its best point as is curve 5 and is obtainable with only a fraction of the cost, time and interference with plant operation as is required for a complete test.

Lacking a current meter or a velocity gage an indicating device may often be improvised at the plant. A rectangle of two by fours covered with wire netting like chicken wire, or even boarded up solid if small in area, may be suspended in a flume of fixed area. The more nearly it approaches the area of the flume

Table II—Efficiency from Current Meter Index

Gate in Tenths on Gov. Dial	1 Kw. Output 12.6-Ft. Head	2 Average Index Velocity I_v	2a Combined Efficiency Assumed	3 Combined Efficiency Figured
10	443	3.05		83.0
9	427	2.75		88.7
8	390	2.45		91.0
7	320	2.15	85	85.0
6	230	1.80		73.0
5	160	1.50		61.0
4				
3				
2				
1	0			