HYDRO· REVIEW

The Magazine of the North American Hydroelectric Industry

Vol. VI, No. III, June, 1987

OPERATIONS AND MAINTENANCE

"Black Box" Developed For Index Testing of Kaplan Turbines

By Doug Albright

A new method for testing Kaplan turbines — the index test box — automatically collects *in situ* operating data without constant supervision or changes in unit generation levels.

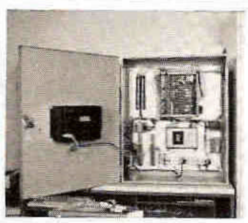
Woodward Governor Company has developed a new method for testing Kaplan turbines using a device called the "index test box." The new method — which uses the index test box in association with an electronic governor — has no inherent delays, nor does it require constant operator supervision.

In this method, blade control is moved from the current 3-D cam to an external test box. Data is automatically collected for several different combinations of gate and blade positions without causing significant changes in flow or generation level. The test box is used to position the blades while the governor repositions the gates to maintain constant generation.

Using this new technique requires a governing system that includes generation feedback in order to maintain generator output at a constant level.

Data Collection

The index test box measures seven different parameters for each test point associated with an index test. These measurements are the actual blade position, the existing cam blade position, gate position, headwater level, tailwater level, generation level, and some indices of flow. Figure 2 is a schematic identifying the transducers used for these measurements.



Woodward Governor's "index test box."

Head measurements are taken from existing head and tailwater transducers located in the powerhouse and installed as part of the electronic 3-D cam. Gross head, which is the difference between head and tailwater levels, is used in all calculations in the index test box. Because flow changes are minimized by the test technique used in the index test box (typically limited to one to two percent), changes in head losses due to trashrack, friction, and velocity head are assumed to be negligible during a test sequence along a constant generation line.

Instead of the standard manometer tubes, a differential pressure transducer is used across the Winter-Kennedy taps to obtain an index of flow. This differential flow measurement is converted to a

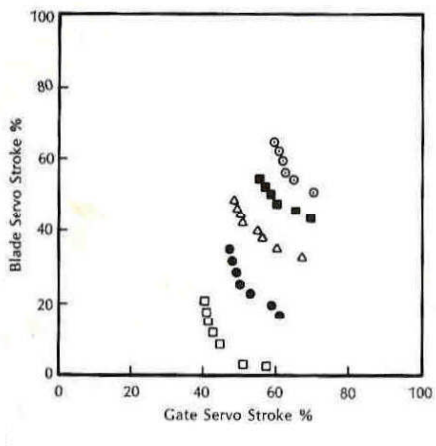


Figure 1. Example of data collected along five constant generation lines for one head level.

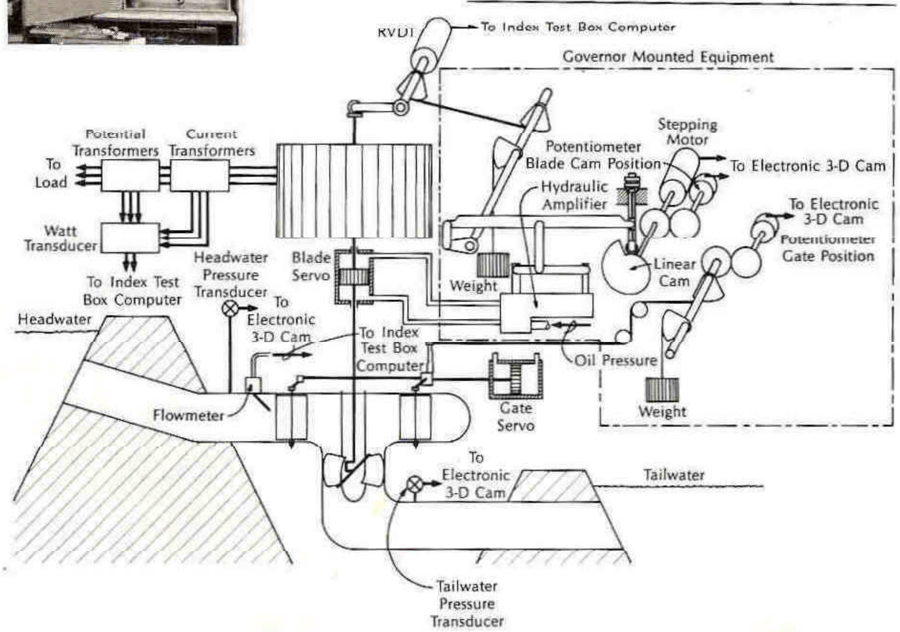


Figure 2. Schematic identifying the transducers used for the following measurements — actual blade position, existing cam blade position, gate position, headwater level, tailwater level, generation level, and indices of flow.

relative flow value by the formula:

$$Q = K\,(Dp)^{.5}$$

Where:

Q = relative discharge in cubic feet per second

K = calibration constant in cubic feet per second

Dp = percent differential pressure

The generator output measurement is made from the watt transducer signal provided to the governor. Each of the blade and gate positions is measured from devices mounted with the governor equipment and used within the electronic 3-D cam system.

Testing Procedure

The index test box is installed by inserting integrated circuit boards into the module rack of the 3-D cam. The circuit boards, connected by a cable to the test box, are calibrated by adjusting several potentiometers on one of the boards while sending simulated transducer signals into the 3-D cam rack. The index test box is then calibrated.

The initial test sequence consists of running the turbine at the blade position specified by the existing electronic 3-D cam relationship. The governor is used to maintain turbine power generation at a constant level. Simultaneous measurements of head, flow, and power are made after steady state operation has been achieved. If pre-set limits of noise from the transducers are exceeded, this test point is discarded and sampling is resumed.

After the base data is successfully recorded at the on-cam position, a series of incremental off-cam variations in blade pitch are tested. These tests are started by

Kaplan Efficiency: Where Does Index Testing Fit In?

What is an Index Test?

Kaplan turbines have variable pitch blades which are adjusted as a function of wicket gate position and net head. Figure 3 is an example of this blade function plotted at five constant net head levels. The ability of a Kaplan turbine to adjust its blade angle, as well as wicket gate opening, allows the turbine to operate at peak efficiency over a much wider variety of operating conditions. However, this flexibility in blade pitch/wicket gate relationship also leads to an infinite variety of settings available for any given set of operating conditions.

Theoretically, the turbine should be operated at settings which result in the best efficiency from the unit. The "best efficiency" blade position for each particular operating condition is determined from the gate and head data stored on either metal or electronic cams for various heads or an electronic 3-D cam device with the data stored in software.

Overall turbine efficiency is directly affected by the accuracy of the cam surface. Test data from turbine model tests are often used to determine the initial cam surface contour for a new turbine. However, actual turbine characteristics may differ from the model, and years of use can create changes to the flow passages. These changes can be significant enough to alter the optimum runner blade and wicket gate relationship.

Index Tests

On an existing unit, an index test can be performed to determine the optimal blade position for a new cam surface. Turbine efficiency testing is described in detail in PTC-18, the ASME Power Test Code for Hydraulic Prime Movers.[1] The purpose of this test code and the procedures it details is to verify turbine efficiency and determine vendor compliance with contract guarantees. In 1949, the Index Method of Testing supplement was added to PTC-18 to cover relative or index testing of turbines.[2] This supplement and its procedures are used to maximize operating efficiency and provide trending information useful for determining proper maintenance intervals.

As the name implies, an index test simply provides a point of reference or a benchmark of performance so that subsequent tests, when compared with the results of earlier index tests, can be used to identify changes in operating performance. The index test results of one turbine are virtually meaningless in comparison with the index test results of any other turbine.

The standard index test method is time-consuming and must be run under very special conditions. Also, setting and making measurements for various combinations of wicket gate and runner blade angles on a Kaplan turbine can require substantial manpower.

Traditionally, these tests are performed by locking the runner blade in position and varying the wicket gate position so that changes in generator output levels and operating efficiencey can be plotted to determine the turbine propeller's efficiency curve. A series of these test points is made with the runner blade at various angles.

Figure 5 is an example of the type of data obtained from such an index test. This data was taken at eight fixed blade positions and a constant head level. These tests are time-consuming, not only because of the repetitive manual setting of gates and blades, but also because of delays resulting from the need to correlate changes in unit generation level with the dispatcher, and waiting for water levels to stabilize once flow changes are made.

However, the increasing availability of new types of automatic equipment for hydraulic turbine testing will reduce some of the problems with manpower requirements and delays. Most of this testing equipment — now available because of the accessibility and performance capabilities of computers — measures actual unit efficiency at any given operating point, based on the methods specified in PTC-18. The ease and repeatability of efficiency measurements are the primary benefits of such equipment.

moving the blades steeper until two consecutive test points indicate a decrease in efficiency or until any of the pre-set limits are exceeded. Blades are then moved in increments toward the flatter direction, again with repeated checks for two consecutive decreasing efficiency readings or exceeding of pre-set limits. Measurements for each incremental variation in blade pitch are recorded after the governor has repositioned the gates to return the power generation level to the set point.

Data Reduction

To determine the peak efficiency blade relationship for a Kaplan turbine, performance data is collected from different combinations of gate and blade positions. All data is grouped by net head. Flow and power values are normalized to a common head using the standard affinity relationships. These relationships are only valid for small ranges of head. Head variations greater than about three percent between the measured and common head cannot be correlated by this method. Corresponding generation and efficiency levels are then computed for each blade-gate pair; these values are evaluated to determine which blade-gate pair will deliver the highest efficiency for existing conditions.

Comparison Tests

In September 1985, a field test was conducted at Clarence Cannon Dam in Monroe City, Missouri. This test, to demonstrate the capabilities of the index test box, included both manual index testing in the classical method, and an index test using the index test box. Test site selection was based on index tests scheduled on the units at this site by the U.S. Army Corps of Engineers.

Clarence Cannon Dam has one Kaplan turbine and one Francis turbine. Soon after both units were placed into commercial service, these initial tests were conducted to calibrate Winter-Kennedy taps, acquire baseline data for later trending of performance levels, and determine the optimum 3-D cam surface for the Kaplan turbine. (Refer to Figure 3, which is the blade function for Clarence Cannon Dam, as defined by the model tests.)

Classical index test procedures for this manual test conformed to the supplement to the ASME Power Test Codes, PTC-18.

When testing turbines, the most meaningful data is acquired when index tests are performed at the turbine's design head. The design head is the head level, specified by the turbine vendor, at which a turbine delivers rated maximum efficiency. For these particular units at Clarence Cannon, the design head is 75 feet. To keep head across the units at this level for the Corps' manual tests, the reregulation dam — located nine miles downstream — was used to raise the tailwater approximately 7.5 feet.

Because the classical index test methods used for the Corps' manual tests resulted in different generation levels and discharge flows at each test point, sufficient time was necessary for tailwater levels to stabilize after each change in gate or blade. All changes to generation were coordinated with the power dispatcher, so that another unit's generation could be adjusted to keep total power constant to the grid.

Of the 70 sets of measurements made during the test, the first eight sets were taken at different load levels with the blades on-cam to document the 'as found' condition of the unit (for 75 feet of head). For the off-cam measurements, the blades were manually positioned at ten percent intervals, with the gates set at several positions on either side of the on-cam line.

In lieu of an absolute flow measurement, predicted efficiencies provided by the turbine and generator manufacturers were used to calibrate the Winter-Kennedy taps. This index of flow was then used to compute indexed values for discharge in the efficiency computations.

From this classical index test (with the turbine tested at its design head of 75 feet), the optimum 3-D cam line for 75 feet was shifted steeper by about eight percent. Figure 4 shows both the initial blade curve and the optimized blade curve, as determined from this test. (The actual test data for these tests at the constant blade positions is shown in Figure 5.)

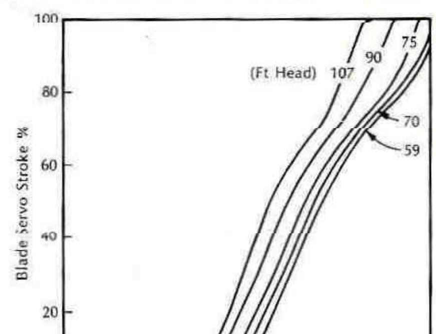


Figure 3. Lines of constant head.

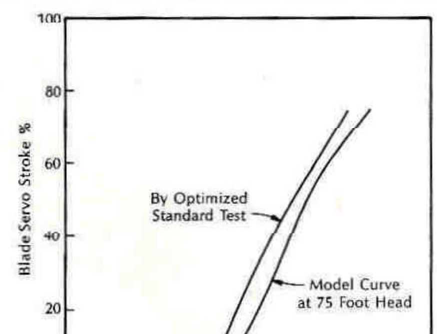


Figure 4. Initial index test results.

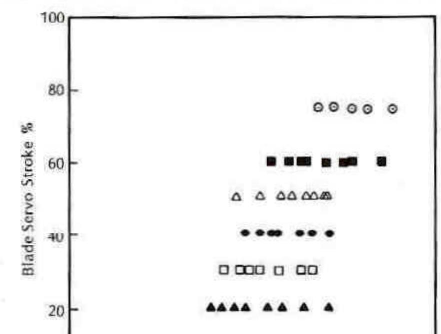


Figure 5. Constant blade data. This data was taken at eight locked blade positions at one head level.

To optimize the rest of the 3-D cam surface, the gate-to-blade lines for the entire surface were shifted this same amount. This index test indicated that an average efficiency increase of approximately one third of one percent could be obtained by installing the new cam surface in the electronic 3-D cam.

The second index test, conducted one week later on the same Kaplan unit, was performed to show that the index test box would identify the same optimum cam profile as the classical test. Results of this second test (using the new index test box) indicated a shift to the 3-D cam surface similar to the shift indicated by the Corps' test. Figure 6 shows the initial model blade curve and the optimized blade curve, as determined by the index test box.

The Corps' classical test took one week and 14 people, the index text box test took one day and one person, although that person didn't need to be present for the entire duration of the test.

For the field test of the index test box, the reregulation dam could not be used to hold the 75-foot design head across the turbine, so the test was conducted at the normal seasonal head of 82.5 feet. This variation in head required some extrapolation of the test data to compare the cam profile shifts.

Because of the differences in head, a direct comparison of the test results using the standard affinity relationships was not possible. Standard affinity relationships were used to adjust head and power values to compensate for small changes in head. By correcting efficiency values to a common head, direct comparisons can be made between efficiency values collected at different heads within a three percent band around the common head.

The Corps' test results indicated that maximum operating efficiency at Clarence Cannon could be achieved by shifting the entire cam surface eight percent steeper (this means that the blade curve for 82.5 feet head should also be shifted eight percent steeper). A similar shift is indicated by the index test box field test data.

Conclusions

A direct correlation between a standard index test and the results of the index test box is not yet possible because of the difference in net head, as described. However, a field test of the index test box demonstrated that it identified a shift in the gate-blade relationship for optimal operation similar to that derived from traditional methods, and that shift was identified with much less effort. Consequently, the results from the initial field tests of the index test box are promising, but further testing of the index test box is planned. A patent application has been filed.

References

1. ASME Power Test Codes, PTC-18-1949, Test Code for Hydraulic Prime Movers, prepared by the American Society of Mechanical Engineers.

2. Index Method of Testing, Supplement to PTC-18, ASME Test Code for Hydraulic Prime Movers, prepared by the American Society of Mechanical Engineers.

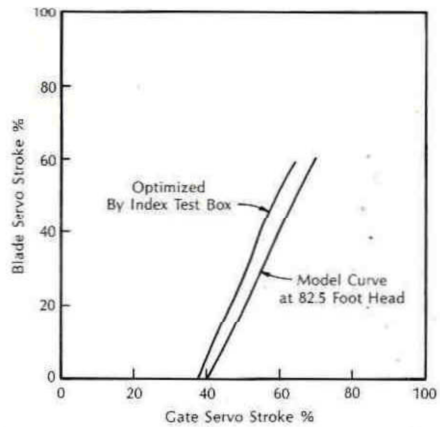


Figure 6. Results of the model and index tests.