INDEX TEST BOX FIELD TEST
DEMONSTRATING ACCEPTABILITY OF THE TEST METHOD

ABSTRACT

An Index Test was conducted at Clarence Cannon Dam, Monroe City Mo. on a Kaplan turbine utilizing accepted methods by the Corps. of Engineers. This test was to determine the optimum nethead-gate-blade relationship for peak efficiency.

This test was observed to get a practical understanding of the method and reasoning behind this testing.

Upon completion of this test, a Woodward Governor Company Electronic 3-D Cam and the new Index Test Box were installed on the unit.

The optimum nethead-gate-blade relationship was determined at six generation levels using the index test box and our new test method.

Correlation of the cam profiles indicated by these two tests demonstrates that our new method works acceptably well for index testing Kaplan turbines.

METHOD: USCE INDEX TEST

Guidelines for this test program and the test results are documented by the reports prepared by Don Sachs of USCE.

CALIBRATION PROCEDURE

Water levels for head and tailwater were manually measured. Then the Sel-Syn transmitters were calibrated to these values.

The unit was dewatered for inspection of the spiral case Winter-Kennedy taps, turbine and gates, and to allow moving the gates and blades full stroke to calibrate all indicators.

The Winter-Kennedy taps were serviced and flushed with water. The manometer board was connected to the taps along with an air supply to blow the water levels down to a convienient level for reading the differential pressure.

Power was read directly from the watt-hour meter, which was presumed to be calibrated. An Autograph 800 recorder was installed and calibrated to agree with the watt-hour meter.

When the unit was operated, the flow conversion constant, K, was selected to agree with the vendor's model test for the peak efficiency value.

METHODS EMPLOYED DURING TEST

This test was performed using classical methods for data collection and reduction. The first procedure was to measure efficiency at 8 different generation levels with the blades operated "on-cam".

The remainder of the tests were of the fixed blade-moving gate and generation type.

Blade position was set using the manual floating lever lifting knob supplied with the mechanical 3-D cam.

Blade position was read from 4 different locations:

1. A fabricated dial indicator at the oil head.
2. Extension of the cable was measured from the cable conduit to a block clamped to the cable.
3. A potentiometer was used to indicate position of the blade restoring weight.
4. The blade indicator dial on the face of the governor.

(Duplicate measurements were taken to allow later verification of any questionable data.)

Gate position was set by loading the unit with the speed adjust to a point above that desired to test. The gate limit was then used to close the gates slightly. The lock rings on the servos were then positioned to block the servos from opening the gates further. The gate limit was raised to allow the servos to run up against the lock rings.

Gate readings were taken from 3 locations:

1. Micrometer readings were taken from the gate servo stroke.
2. A potentiometer on the gate restoring shaft.
3. The gate indicator dial on the face of the governor.

Flow measurements were made using a manometer board constructed by site personnel for this index test. The manometer board is a differential pressure measuring device that indicates from .1 inch to 10 ft. of water column. The differential pressure is taken from the Winter-Kennedy taps on the spiral case of the turbine. Common mode pressure from the spiral case is equalized with air pressure blown onto the top of the water tubes (aprox 30 psig) to allow reading the water columns at convenient levels.

Eleven readings were taken on 30 second intervals from all test stations. Readings from the 4 manometer tubes were reduced to an average value, then the square-root of this average was taken. This result is then multiplied by the calibration constant, "K" which is used to scale this differential pressure to actual discharge flow.

Power was read from two indicators:

1. A Boky-Doty meter was connected to the rotating watt-hour meter. (The Boky-Doty meter consists of a lamp and sensor that are positioned to read the holes in the rotating watt-hour disc.)

   This equipment requires an operator to start and stop measurements.
2. An Autograph 800 was installed to record generation level. (An Autograph 800 is a data recorder that was installed to monitor and transmit data from the generators at Clarence Cannon to the operators at Truman dam.)

This test also required an operator to synchronize data collection and compute the average value of the samples taken.

Headwater and tailwater levels were measured from the powerhouse instruments and converted to nethead. For this test nethead was maintained at 75 ft., as close as possible. All measurements were taken manually, with synchronization of data collection provided by telephone communication between test personnel.

TEST STATIONS FOR TEST PERSONNEL

(1.) Two men in the turbine pit to lock the servo stroke with the locking rings and measure blade stroke with micrometers.
(2.) Two men at the oil head on the generator to measure the blade restoring cable extension and the indicator dial fabricated for these tests.
(3.) Two men at the governor to position the blades, and read the gate and blade indicators on the governor.
(4.) Three men at the manometer board, two to read the manometer tubes, and one to call cadence, record data, and calculate average value and square root of test data.
(5.) Two men reading the two generation indicators: the Boky-Doty meter and the Autograph 800 data recorder.
(6.) An operator was brought from Truman to set generation level/gate position, record total generation and water levels, coordinate all test efforts, and assure safe operation throughout the test.
(7.) Two engineers from Omaha District of USCE to reduce and evaluate data, and direct the test effort to achieve the most meaningful data possible from the testing.

EQUIPMENT NEEDED FOR TEST

(1.) Micrometers to measure the gate and blade stroke. These were read to .01 in. resolution.
(2.) A manometer board to read the differential pressure across the Winter-Kennedy taps on the spiral case. This was read to the nearest .01 foot. (This board was constructed by site personnel specially for the USCE index test.)
(3.) A dial indicator was fabricated for blade position and installed to indicate the blade position from the extension of the blade restoring cable. This can be read quite easily to .5 percent of blade position.
(4.) Blade restoring cable stroke was measured from the cable tube end to a block clamped on the cable with a dial indicator. This measurement was made to within .001 in..
(5.) A potentiometer was installed to indicate blade restoring cable stroke. This reading accuracy is within 1 percent. (This potentiometer was powered with the Electronic 3-D Cam isolated power supply and measured with a volt meter.)
(6.) Gate position was read also from a potentiometer on the gate restoring shaft, and again to within 1 percent. (This potentiometer was also powered by the Electronic 3-D Cam and measured

with a volt meter.)
(7.) Powerplant instrumentation was used to measure and record head and tailwater levels to within .01 feet.
(8.) Two types of power measuring equipment were utilized.
1. Boky-Doty meter was installed on the rotating watt-hour meter.
2. Autograph 800 that was installed to output generation data to the operators at Truman dam during remote operation.

DATA REDUCTION TECHNIQUES EMPLOYED FOR CLASSICAL TEST.

Data reduction for this test was according to the classical methods and is documented in the the test report from USCE.

INDEX TESTING USING INDEX TEST BOX

INSTALLATION OF 3 D CAM

An electronic 3-D cam is required in order to index test a turbine with the automatic index test box. The Kaplan unit at Clarence Cannon was not already equipped with an electronic 3-D cam. As part of the Index Box field test an electronic 3-D cam was installed and calibrated as directed in Woodward Governor Company field service instructions.

CALIBRATION OF TRANSDUCERS

The Sel-Syn transmitters were manually run through their full span and voltage outputs from the transmitter pots recorded.
These values were used to calibrate the index test box from 0 to 100% span of the water level transducers.

The spiral case Winter-Kennedy taps were not reinspected at this time, but the unit was dewatered to allow moving the gates and blades full stroke to calibrate the 3-D cam and index box.

The differential pressure transducer for the Winter-Kennedy taps was calibrated to give 4 ma. when the bypass valve was opened, and 20 ma. when the differential pressure was 6 feet of water column.

To calibrate the watt transducer input, the index test box was connected to the electronic 3-D cam and the unit run up to full power. Voltage measurements were taken from the watt transducer at speed-no-load and full output.

METHODS EMPLOYED DURING TEST

With the unit on line operating normally, (steady state) the index box was enabled and started. The measurement process consisted of 5 samples of 8 measurements each. The index test box determined steady state using the standard deviations of the data sets. Uniqueness of a data point was determined by comparing this point to an array compiled in memory of all previously tested data points.

Once an index test is initiated the correct blade tilt voltage was calculated and output to the 3-D cam, then the blade tilt relay was activiated.

Now under control of the index test box, the blades remained at the position assumed under "on-cam" conditions.

The data collection routine took another set of data, which then replaced the first set. (This is the same operating point as the "on-cam" position, but this test point has a fixed blade, instead of the blade follows gate relationship.)

The index test box then moved the blades to a position 3% steeper than the first point and repeated the evaluation for steady state.

Once steady state was reached a new data point was collected.

This procedure was repeated 3 times, then the data points taken were evaluated for a peak of efficiency and two decreasing efficiency points in the steeper blade direction. (The amount that the efficiency must decrease is an input parameter during calibration.)

If a peak and two decreasing efficiency points were not seen by the index box, the blades would be moved yet another 3% steeper and the data collection repeated.

When the first test, (the peak and two decreasing efficiency points in the steeper blade direction) was satisfied, the data set was evaluated for a peak and two decreasing efficiency points in the flatter blades direction.

If a peak and two decreasing efficiency points were not seen in the steeper blades direction, the blades were moved 3% steeper and the data collection routine executed again.

When the index test box had taken enough data to satisfy both tests (an efficiency peak and two decreasing values on either side of the peak) the blades were released from blade tilt to normal operation.

TEST STATIONS FOR TEST PERSONNEL

This entire procedure takes place automatically, without operator supervision or direction, but was observed by two people during all index testing to insure a safe field test.

In the final configuration of the index test box, the only operator involvement with the index test box is that the operator be aware when the index test box is performing an index test, and the generation level not be changed until the index test box has completed the current test, been disabled, or shut off.

EQUIPMENT NEEDED FOR TEST

A mod 2 electronic 3-D cam.
An automatic index test box.
An electronic power feedback governor.
Input signal from the Watt Transducer amplifier.
A pressure transducer across the Winter-Kennedy taps.

DATA REDUCTION TECHNIQUES EMPLOYED IN INDEX TEST BOX.

RELATIVE DISCHARGE

The pressure transducer was installed across the Winter-Kennedy taps that gave the greatest differential pressure when the unit was operating at 100% generation level.

This turned out to be legs 3 and 4.

The formula for relative discharge used is identical to the formula used by USCE for their index test:

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

Where:

Q = relative discharge (cfs)
K = 724.5 (calibration constant)*
Dp = differential pressure (percent of full span)

* The calibration constant used for the index test box index test differed from the constant used by the USCE index test in that for the USCE test, Dp was in feet of water column and the index box treats this parameter as 0 to 100 percent of full span.

CALIBRATION CONSTANT

The calibration constant for the USCE test was selected simply to derive a correlation with the absolute efficiency predicted by the vendor's model tests for the unit.

The index test box calibration constant was selected simply to get a correlation with the efficiency measurements by the USCE test and the index test box tests.

GROSS HEAD

Gross head across the unit was computed from the inputs from the headwater and tailwater transducer systems.

The data collected is in percent of transduced span, not turbine design span.

Input data is in 0 to 100 percent of the measured head and tailwater spans. These two are scaled against one another to get the percent of full transducer span.

Calculations:

percent of span = Hspan * cals(2,5) + 100 - Tspan * cals(3,5)

Where:

percent of span = percent of the 73.1 foot transduced span.
Hspan = input to headwater channel, 0 to 100%
Tspan = input to tailwater channel, 0 to 100%
cals(2,5) = percent of full measured span of full

headwater span.

cals(3,5) = percent of full measured span of full tailwater span.

100 = representation of 100% of tailwater span, used because to combine headwater and tailwater levels, the tailwater must be considered from the top of it's span down, when the transducer measures from the bottom up.

To convert to feet of gross head:

Gross head = percent of span * 73.1 + 59.4

Where:

gross head = headwater elevation - tailwater elevation.
percent of span = percent of the 73.1 foot transduced span.
73.1 = the transduced span
59.4 = Untransduced, unchanging nethead between the two transducer spans.

Energy input to the turbine:

energyin = Q * 62.4 * gross head

Where:

Q = unit discharge (cfs)
62.4 = weight of a cubic foot of water
gross head = result of previous equation.

Energy out of the generator:

energout = Wtout * 33 * 10^{6} / 745.4

Where:

Wtout = level read from watt transducer amplifier, indicated in 0 to 100% of full output.

$33*10^{6}$ = 100% output of generator in horsepower.

745.4 = foot pounds per horse power for comparison with result of energyin calculation.

Efficiency then becomes:

energyout / energyin

Nethead corrections to a single nethead have not yet been done for the field tests. The primary goal was to demonstrate the index test procedure in terms of maximizing efficiency by finding the optimum nethead-gate-blade relationship.

Nethead correction equations are:

1. To convert power output:

corrected power = (desired head)$^{1.5}$ * measured power

(actutal head)

Where:

desired head = head that all others are being corrected to.

actual head = head measured for specific test point being adjusted.

measured power = generator output for specific test point being adjusted.

2. To convert flow:

$$\text{corrected head} = \frac{(\text{desired head})}{(\text{actual head})}^{.5}$$

SIMILARITIES AND DIFFERENCES BETWEEN THE TWO INSTRUMENTATION METHODS.

Both methods instrument the same set of parameters from the unit under test:

1. Headwater
2. Tailwater
3. Gate stroke
4. Blade stroke
5. Water flow
6. Generation level

Method of reading these parameters were:

1. Headwater for both tests was read from the same indicator system. The manual test read the dials on the selsyn reciever, while the index test box was connected to the potentiometer on the selsyn reciever output shaft.
2. The tailwater system is identical to the headwater system, and was also read manually from the dials and electronically from the potentiometer on the selsyn drive shaft.
3. During the USCE test, gate stroke was measured with micrometers from the gate servo extension in the turbine pit. The index test box input was from the gate restoring shaft potentiometer, which is the normal input to the electronic 3-D cam.
4. The blade position was read from the fabricated dial at the oil head for the manual index test. The index box blade position input was from the output of the electronic 3-D cam, the linear riser cam elevation. *

* (this was the only unsatisfactory input to the index test box during the test.

Blade positioning hysteresis was not accomodated by the index test box, and the data collected has some hysteresis identifiable in the constant efficiency plots.
The cure for this would be a linear transducer on the blade

restoring weight to indicate true blade position to the index test box)
Cross-calibration charts were drawn to compensate for the offset and gain shift of the mechanical amplifier in the blade positioner.

5. Water flow for both tests was read from the Winter-Kennedy taps across the spiral case.
The manual method required 3 men to observe the manometer tubes, while the index box read a differential pressure transducer mounted across the Winter-Kennedy taps.