1. **INTRODUCTION.** This report documents the test procedure and results for the initial index testing of the Kaplan turbine at Clarence Cannon Power Plant on 17 and 18 September 1985. The testing was performed under the direction of the U.S. Army Corps of Engineers, Omaha District, Hydropower Design Center, for the St. Louis District.

1.1 The powerhouse structure is part of the dam; this results in a short water intake passage for the unit. There is no long penstock therefore a high confidence level method of determining discharge such as the Gibson test could not be performed to evaluate performance of the unit. The best method of approximating discharge is from the turbine manufacturer's model tests. The results of the index testing were adjusted to be consistent with the manufacturer's prediction for peak efficiency of the prototype unit based on the model tests.

1.2 The purposes of index testing Unit No. 1 turbine were: (1) to determine constants for calibration of the unit's flowmeter, (2) to document initial performance so that future periodic testing can be performed to determine if operation is at peak efficiency, and (3) to determine the proper relationship between gate opening and blade angle so that the electronic cam can be programmed to operate the unit at peak efficiency.

1.3 At the time of index testing, the unit had been in service for 20 months. The gross head at the plant varied between 75.82 feet and 77.47 feet during testing. Test results are adjusted for 75 feet net head across the unit. In addition to documenting the initial index testing, this report is intended to give direction for future periodic index testing for comparative purposes.

2. **PERTINENT DATA.**

Turbine

Type	Kaplan (vertical)
Rating	43,500 hp at 75 ft. net head
Rated peak efficiency	92.2 percent
Manufacturer	Allis-Chalmers Corp

Generator

Type	Synchronous
Rated Speed	127 rpm
Max Rating	32,684 kW
Manufacturer	General Electric

Governor

Manufacturer	Woodward Governor Co.
Type	Mechanical w/electronic 3D cam

Project

Min operating pool	590.0 ft. m.s.l.
Max operating pool	638.0 ft. m.s.l.
Max tailwater el	528.0 ft. m.s.l.
Min tailwater el	521.0 ft. m.s.l.

3. RESULTS.

3.1 Flowmeter Calibration Constants. Discharge is normally determined by using the Winter-Kennedy system. The Winter-Kennedy system consists of one high pressure piezometer tap located at the outer periphery of the spiral case and three low-pressure taps located at the inner periphery of the spiral case. Discharge is proportional to the square root of the pressure differential between any two of the taps.

Normally the two taps used to determine discharge would be the outer (high-pressure) tap and the inner (low-pressure) tap which would show the largest pressure differential. For this unit, tap No. 4 (outer) and tap No. 3 (inner) would be used since they show the largest differential. However, calibration constants have been calculated for a combination of any two of the taps. This information may be useful in the event that one or two of the taps would become unserviceable.

The calibration constants are listed below and would be used with the equation, $Q = K\ (Dp)^{0.5}$, see paragraph 5.1.

Leg Nos.	Calibration Constant
3 & 4	2381
1 & 2	6723
1 & 3	4575
1 & 4	2789
2 & 3	6245
2 & 4	2576

The peak efficiency of the turbine, calculated using these constants, is consistent with the peak efficiency predicted for prototype unit from the manufacturer's model test, which is 92.2%.

As long as turbine efficiency and trashrack friction loss remain the same and the blade control cam is maintained in proper adjustment, turbine discharge can be determined as a function of gross head and generator output. This relationship is shown on Graph No. 1, Appendix A.

3.2 Optimization of Blade Control Cam. A Kaplan turbine can operate efficiently over a wide range in power. It can do so because the pitch of its blades can be varied with its wicket gate opening and head. For a specific power output and head, there is a combination of gate opening and blade pitch that is most efficient.

Blade pitch of this unit is controlled by an electronic cam in the governor. The cam inputs are gross head and wicket gate opening. A computer chip based on model test data is used to set blade angle. Model test data gives a good approximation of the best blade pitch, but index testing can sometimes show a better blade and gate relationship.

The results of these tests indicate that the blade pitch for this unit should be about 8 percent more open than the model tests indicate for best efficiency. (See graph No. 2 - Appendix A.) Controlling the unit's blades as the index test data indicates will result in an efficiency increase of about 1/3 percent.

3.3 **Documentation of Turbine Performance.** Periodic index testing will be done to determine if performance is as expected. The initial testing performed per this report was necessary to determine a base condition for later comparisons. Any abrupt performance losses that may occur in the future could be detected, and gradual performance losses because of corrosion, cavitation, and cavitation repair could also be detected.

Graph No. 3 - Appendix A shows the efficiency relative to power output. Flowmeter calibration constants were adjusted to result in a calculated peak turbine efficiency of 92.2 percent, the same as was predicted from the manufacturer's model test. Efficiency is dependent on discharge. Therefore, any change in discharge measurement will result in a change in calculated efficiency. If future index testing shows a change in discharge and efficiency, it is recommended that discharge also be determined using alternate combinations of the Winter-Kennedy taps. It is possible that one or more of the taps will become inoperative, or at least require recalibration in the future.

Graph No. 5 - Appendix A shows the capacity as a function of blade tilt and servo-motor stroke. The blade tilt and servo-motor stroke relationship for best efficiency at 75 feet net head is also plotted on that graph. This graph serves two purposes: (1) It documents performance independent of discharge, and (2) It documents performance if the blade tilt and servo-motor stroke relationship are not correct. (A slight change in blade tilt will affect capacity significantly.)

Future periodic testing should be performed when the head is within 3.0 feet of the head during the initial testing for a good comparison. It is also recommended that comparisons be made with both the capacity and efficiency results in this report. Based on the scatter of data during the initial testing, it is estimated that consistency of efficiency measurements could vary by ±1.0 percent for future tests performed at any one power output. It is estimated that measured capacity could vary by ±500 hp for any combination of servo-motor stroke and blade tilt. Testing at low power outputs may not be of any value if the plant is only rarely operated that way; however, several tests should be made at gate openings at which the plant is usually operated. The results of only one test may not be representative of the true performance of the unit because of data inconsistencies.

4. **TEST PROCEDURE.** The following paragraphs describe the procedure used to gather data. Raw data is contained in Appendix E, and a listing of test personnel is contained in Appendix D.

4.1 **Wicket Gate Opening.** Wicket gate opening was set with the governor. The servo-motor lock nut was then positioned to prevent the gates from opening further and the governor was set to open against the locknut to ensure that the gate opening would remain constant during any one test. Servo-motor position was measured to the nearest 0.01 inch and converted to percent of full stroke (which is 18.75 inches). As a backup, wicket gate opening was also recorded from the governor cabinet display and as a voltage from the electronic cam input.

4.2 **Blade Tilt.** Blade tilt was controlled independently from wicket gate opening by adjusting the output voltage of the electronic cam. Blade tilt was measured as a percent of maximum tilt as displayed at the oil head dial. Dial movement at the oil head is proportional to position of the blade tilt restoring cable, which was measured as a backup. Blade tilt displayed on the governor cabinet and electronic cam output voltage were also recorded as backups.

4.3 **Lake Elevation.** Lake elevation was recorded from the control room display at the beginning and end of each test (5-minute duration) and averaged. The control room display was calibrated prior to testing.

4.4 **Tailwater Elevation.** Tailwater elevation was recorded from the control room display at the beginning and end of each test (5-minute duration) and averaged. The control room display was calibrated prior to testing.

4.5 **Trashrack Friction Loss Data.** It was assumed that the trashracks were clean but the following procedure was used to gather data so that hydraulic friction loss could be calculated. The unit was operated near full output so that a high discharge would be maintained to produce the maximum head loss through the trashracks for accurate measurement. Surface depression compared to lake elevation was measured at the gate slots. (The surface depression was 0.56 foot during test number 55 with a relative discharge of 5345 cfs.

4.6 **Generator Output.** Generator output at unity power factor was determined with a wattmeter counter. The wattmeter counter counted the number of full revolutions of the wattmeter disk for the generator over approximately a 5-minute time duration. Time was measured to within 0.001 seconds. The wattmeter had been calibrated prior to testing. As a backup, generator output was also determined on the Autograph 800, but time could only be measured to within ±1 second which over a 5-minute test results in a potential inaccuracy of up to ±0.3 percent. In cases where the power determined by both methods differed by more than ±0.3 percent, it was assumed that the wattmeter counter had malfunctioned and the Autograph 800 measurement was used. Volts, current, power, and megavars were also recorded from the control room display.

4.7 Turbine Discharge Data. The Winter-Kennedy system and a compressed air-over-water manometer were used to determine relative discharge. The manometer had four clear plastic tubes each 2 inches in diameter with each leg of the manometer connected to one of the Winter-Kennedy taps. Ten readings at 30 second intervals were taken during each test and averaged. The differential between tap Nos. 3 and 4 was largest and was used for discharge measurement.

4.8 Analyzing Data During Testing. It was necessary to analyze data during testing so that the data gathered could be checked for adequacy to determine if additional tests were required. For analyzing data in the field, both efficiency and capacity were based on gross head and net generator output. (Field results are included in Appendix E.)

5. EVALUATION OF DATA. Relative turbine performance was documented by drawing performance curves through sets of data points representing the individual tests. The calculations to determine data points for each test are described in 5.1 and the method of drawing performance curves is described in 5.2.

5.1 Calculations. The calculations presented in the following paragraphs were used to determine data points to represent the results of each individual test. This calculated data is shown in Appendix B. Actual calculations were performed using a multiplan program on an IBM desktop computer. The disc which records data and equations will be kept in MROED-DB files.

5.1.1 Relative Discharge. Relative discharge was calculated using a calibration constant of 2381 in conjunction with the differential pressure between taps Nos. 3 and 4 of the Winter-Kennedy system. The applicable equation is:

$$Q = K(D_p)^{0.5}$$

where

Q = relative discharge (cfs)
K = 2381 (calibration constant)
D_p = differential pressure (feet)

5.1.2 Calibration Constants. A calibration constant of 2381 was assigned for use in the discharge equation above, using taps Nos. 3 and 4 of the Winter-Kennedy system. This results in the prototype's calculated efficiency matching the efficiency predicted by the model tests. Calibration constants were also calculated for the other five combinations of taps in the Winter-Kennedy system. The applicable equation is:

$$K = Q/(D_p)^{0.5}$$

where

K = calibration constant (no units)
Q = relative discharge (cfs)
D_p = differential pressure (feet)

Individual constants calculated for each test were averaged to give the best approximation for calibration constant to use with the flowmeters.

5.1.3 **Gross Head.** The applicable equation is:

$$H_g = E_L - E_{tw}$$

where

H_g = gross head (feet)
E_L = average lake elevation during test (feet m.s.l.)
E_{tw} = average tailwater elevation during test (feet m.s.l.)

5.1.4 **Draft Tube Velocity Head.** The applicable equation is:

$$H_v = v^2/2g$$

where

H_v = velocity head at draft tube exit
g = acceleration of gravity (32.17 ft/sec^2)
V = Q/A
Q = discharge (cfs)
A = area at draft tube (1242 ft^2)

5.1.5 **Trashrack Friction Loss.** The applicable equation is:

$$L_f = D_s + H_v$$

where

L_f = trashrack friction loss (feet)
D_s = surface depression at gate slots (feet)
H_v = $v^2/2g$ (velocity head at trashracks)
g = acceleration of gravity (32.17 ft/sec^2)
v = Q/A
Q = turbine discharge (cfs)
A = area at gate slots (1056 ft^2)

5.1.6 **Net Head.** The applicable equation is:

$$H_{net} = H_{gr} - L_f - H_v$$

where

H_{net} = net head (feet)
L_f = trashrack friction loss (feet)
H_v = deaftube velocity head (feet)
H_{gr} = gross head (feet)

5.1.7 **Turbine Output.** The applicable equation is:

$$P_t = (Pg/Eg) \times 1.341$$

where

P_t = power output of turbine (horsepower)
P_g = power output of generator (kilowatt)
E_g = efficiency of generator

Generator efficiency is per generator acceptance tests perform in August 1984 (see Appendix D).

5.1.8 **Turbine Output at 75 Feet Net Head.** The applicable equation is:

$$P_{75} = P_t \times (H_{net}/H_{6R})^{1.5}$$

where

P_{75} = turbine power at 75 feet net head (horsepower)
P_t = turbine power during test (horsepower)
H_{net} = net head (feet)
H_{gr} = gross head (feet)

5.1.9 **Turbine Discharge at 75 Feet New Head.** The applicable equation is:

$$Q_{75} = Q \times (H_{net}/H_{gr})^{0.5}$$

where

Q_{75} = turbine discharge at 75 feet net head (cfs)
Q = turbine discharge during test (cfs)
H_{net} = net head (feet)
H_{gr} = gross head (feet)

5.1.10 Turbine Efficiency at 75 Feet Net Head. The applicable is:

$$E_t = (P_t \times K_1) / (H_{net} \times Q \times D)$$

where

E_t = efficiency of turbine
P_t = turbine power during test (horsepower)
K_i = 550(ft lbs/sec hp)
H_{net} = net head (feet)
Q = turbine discharge during test (cfs)
D = density of water, 62.4 lbs/fr^3

5.2 Drawing Performance Curves. Initially, data points for each individual test were calculated for 75 feet of net head across the turbine as described in 5.1. These data points were plotted on graphs No's 4, 5, 7, 8, and 9 showing discharge, power, and efficiency versus servomotor position. A curve was drawn through each of the 9 sets of points representing a particular blade tilt. It was required that the curves on the discharge, power, and efficiency graphs for a particular blade tilt be related to each other by the efficiency equation. By a trial and error process, using a multiplan program on a desk top computer, the curves were made as smooth as possible and made to fit the individual data points as well as possible on each graph.

Curves for each blade opening, fitting the above efficiency equation were plotted on graph No. 3 showing power versus efficiency. Data points for servomotor position and blade tilt for best efficiency were taken from graph No. 3 to plott the curve shown on graph No. 2. Data was also taken from the manufacturers model test report and plotted on graph No. 2 for a comparison. The results of this comparison is discussed in 3.2.

Using data points from graph No's. 4 and 5 data points were corrected for 75 feet of gross head and used to draw the 75 foot gross head curve of graph No. 1 which shows turbine discharge as a function of the unit's generator power output. Addition curves for other heads were calculated and drawn using the relative relationship between discharge and power at different heads shown in the model test report.