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of Engineers**  
Omaha District

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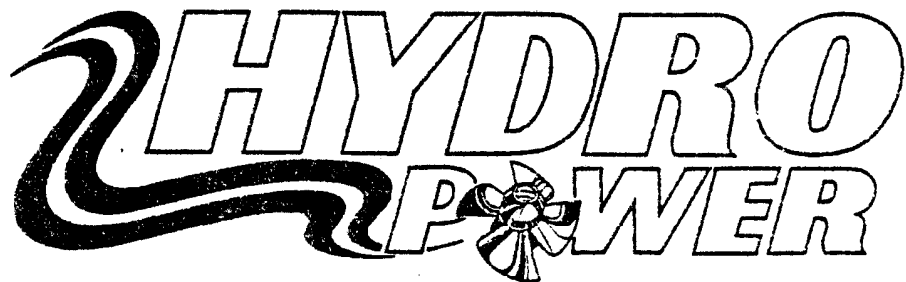
**REPORT ON:**

**INITIAL INDEX TESTING  
OF THE KAPLAN TURBINE**

**CLARENCE CANNON POWER PLANT  
SALT RIVER, RALLS COUNTY, MISSOURI**

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**INITIAL INDEX TEST  
OF THE KAPLAN TURBINE**

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PROCEDURE FOR INDEX TESTING AT CLARENCE CANNON POWER PLANT

1. Purpose of Index Testing. Index testing is a relative efficiency testing method applicable to the Clarence Cannon units. It is necessary to determine the optimum blade angle for any gate opening and head while generating with the Kaplan unit. Periodic index testing is desirable to verify by comparison with previous data that both units are operating at optimum efficiency. Index testing is also necessary to determine the optimum gate opening for pumping with the Francis unit over its range of operating heads. Flow meters must also be calibrated which requires index testing and equating the discharge to the manufacturers model test results.

2. Discharge Determination. The basic equation used to determine efficiency of a hydraulic turbine is as follows:

$$Eff_t = 550P/QWH$$

Where  $Eff_t$  = Turbine Efficiency  
P = Turbine Output, hp  
Q = Turbine Discharge cfs  
W = Weight of cubic ft. of water  
H = Net Head Across Turbine

At Clarence Cannon, there is no long penstock so that a high confidence level method of determining discharge such as the Gibson or Salt Velocity Test can be performed. The best method of approximating discharge is from the manufacturers model tests. Discharge will be solved, in the above equation, assuming that the maximum efficiency predicted by the model tests will in fact be the maximum efficiency of those units. It will be assumed that discharge is proportional to the square root of the differential across the pressure taps used for flow measurement. After initial testing is completed and data analyzed, constants will be calculated for and permanently assigned for the flow measurement taps of the units so that discharge will be assumed to be equal to the constant times the square root of the pressure differential.

For determination of the above constant, head will be net head across the unit, velocity head of the discharge and head loss measured across the trashracks will be subtracted from the gross head to arrive at the net head. Power will be equal to generator output plus generator losses. After the discharge coefficients have been determined as described above then some simplifications will be made for determining efficiency. Those simplifications will be using gross head rather than net head and using generator output rather than turbine output. In effect the efficiency determined as an end result of index testing will be a total unit efficiency.

### 3. Kaplan Unit-Specific Requirements.

a. General Discussion. Two types of index testing are required for the Kaplan Unit. The first type serves the purposes of collecting data to calibrate flowmeters, verifying that the blade angle gate opening relationship is correct, and establishing base data to document initial performance of the unit. That testing should be performed at head conditions so that the unit is not generator limited. Testing at one head condition should be adequate.

The second type of test is a periodic test to verify that the unit is operating as expected. That testing needs to be performed at a head within 5 feet of previous testing so that a good comparison of efficiency and capacity can be made. Periodic testing should be done at least annually.

b. Head. Reservoir and tailwater elevations will be taken from the governor input. This will be sufficiently accurate provided that the calibration is checked before testing. This is consistent with the purpose of determining if any changes need to be made in the blade angle cam for that unit. Head during testing will be assumed to be the average of the difference

between reservoir elevation and tailwater elevation at the beginning and at the end of the test. Loss measured across the trashracks will be considered for initial testing to assign a constant to the pressure taps. Tailwater will be held to within one foot by control of the regulation dam gates for a set of tests for a specific head.

c. Power. Power will be measured at the generator watt-meter. Turns of the rotating disc will be counted over approximately five minutes, the exact time will be measured, and the average output calculated. A watt-meter counter will be used for that. Power factor, voltage, and amperes will also be recorded.

d. Discharge. Discharge will be determined as described in Section 2 where discharge will be assumed to be equal to a constant times the square root of the differential across the pressure taps. The pressure taps to be used in this case will be the two Winter-Kennedy taps which produce the largest differential. Data will also be recorded for the other two Winter-Kennedy taps. The differential will be measured with an air over water manometer. Differential readings will be read at 30 second intervals for 5 minutes and then averaged.

e. Water Temperature. Since water temperature in the reservoir can vary by about 50 degrees, water temperature will be measured at the raw water inlet and the density of water for that temperature will be used in the efficiency equation.

f. Gate Opening and Blade Angle The unit will initially be tested at 10 percent intervals in gate openings between 30% and 100% with blade angle at the "ON-CAM" position providing that generator capacity is not exceeded. Servo-motor position will be measured to the nearest 0.01 inch. Blade angle position will be measured indirectly from cam follower position, governor

cable position, and position of the oil head indicator.

After that tests will be made for at least 49 other combinations of wicket gate opening and blade angle. The cam follower will be adjusted manually to set the blades for at least seven different positions varying from flat to full open. At least seven tests will be performed at each blade angle at different gate openings. The exact tests points will depend on head conditions. The gate opening will be set at approximately the on-cam position and at six other positions using approximately 2 1/2% intervals. Blade angle and gate opening will be measured as in the above paragraph.

Tests should be made periodically to verify that the unit is performing as expected. For that purpose the tests will be conducted as explained in the first paragraph of this section.

g. Method of Analyzing Data The test points will be plotted on a graph of efficiency versus power. That will indicate if the cam is controlling the turbine blades properly for the best efficiency. For periodic testing blade angle wicket gate relationships can be compared to the initial tests to verify that cam adjustments have not changed. Also for periodic testing results can be compared with the above graph or as capacity or efficiency versus gate opening.

#### 4. Francis Unit-Generating Mode-Specific Requirements

a. General Discussion. The unit should be initially tested to collect data to calibrate the flowmeters and to document initial performance of the unit. That should be done at head conditions so that the unit is not generator limited. Periodic testing should then be done at least annually to verify that the unit is operating as expected. That testing needs to be performed at a head within five feet of previous testing so that a good

comparison can be made.

b. Head Reservoir and tailwater elevation will be taken from the governor input. This will be sufficiently accurate providing that the calibration has been checked before testing begins. Tailwater will be assumed to be the average of the difference between reservoir elevation and tailwater elevation at the beginning and end of each test minus the loss measured across the trash racks. Head will be held to within one foot by control of the reregulation dam gates for a set of tests for a specific head.

c. Power. Power will be measured at the generator watt-meter. Turns of the rotating disc will be counted over approximately five minutes, the exact time will be measured, and the average output calculated. A watt-meter counter will be used for that. Power factor, voltage and amperes will also be recorded.

d. Discharge. Discharge will be determined as described in Section 2 where discharge will be assumed to be equal to a constant times the square root of the differential across the pressure taps. The pressure taps to be used for this case will be the two Winter-Kennedy taps which produce the largest differential. Data will also be recorded for the other two Winter-Kennedy taps. The differential will be measured with an air over water manometer. Differential reading will be taken at 30 second intervals for 5 minutes and averaged to determine discharge.

e. Water Temperature. Since water temperature in the reservoir can vary by about 50 degrees, water temperature will be measured at the raw water inlet and the density of water for that temperature will be used in the efficiency equation.

f. Gate Opening. The unit will be tested at 5 percent intervals in servomotor stroke between 30% and 100% providing that generator capacity is not exceeded. Opening will be controlled with the governor and measured to

within 0.01 inch for servomotor stroke. This is considered necessary, as experience with other units shows that differential across the pressure taps for determining discharge sometimes does not remain constant which can invalidate efficiency comparisons. This will assure that gate opening can be compared to capacity if test to test discharge appears to be uncertain.

g. Method of Analyzing Data For analyzing data the purpose of the test should be kept in mind; that is to provide base data so that future testing will show by comparison any loss in performance of the unit. For that purpose, data is best either shown graphically to show both capacity and efficiency versus gate opening.

#### 5. Francis Unit Pumping- Node Specific Requirements

a. General Discussion The unit should be initially tested to collect data to calibrate the flowmeters, to document initial performance of the unit and to verify that gate opening is optimum for the head conditions. That should be done for at least twodifferent head conditions. A periodic check should be made at least annually to verify that the unit is operating as expected.

b. Head Reservoir and tailwater elevation will be taken off the governor input. This will be sufficiently accurate providing the calibration has been checked before testing begins. This is consistent with the purpose of optimizing the cam in the governor which is used to regulate the gate opening during pumping. Head will be assumed to be the average of the difference between reservoir elevation and tailwater elevation at the beginning and end of each test. Tailwater will be held to within one foot by by control of the spillway gates for a set of tests at a specific head.

c. Power. Power will be measured at the motor watt-meter. Turns of the rotating disc will be counted over approximately five minutes, the exact time



will be measured, and the average output calculated. A watt-meter counter will be used for that.

d. Discharge. Discharge will be determined as described in Section 2 where discharge will be assumed to be equal to a constant times the square root of the differential across the pressure taps. The differential will be measured on an air over water manometer. Differential readings will be taken at 30 second intervals for 5 minutes and averaged to determine discharge.

The manometer will be connected as follows:

1. The first leg of the manometer will be connected to the four taps located in the throat area of the draft tube. Any tap differing in pressure from the other three by more than 10% of the velocity head will be isolated from the manometer.
2. The second leg will be connected to the two taps just upstream of the draft tube gates.
3. The third leg will be connected to the two taps just downstream of the draft tube gates.
4. The fourth leg will be connected to the draft tube drain line or the tailwater well.

Readings will be taken for all four legs of the manometer but differential to calculate discharge is expected to be between the first and second leg.

e. Water Temperature. Since water temperature in the reservoir can vary by about 50 degrees, water temperature will be measured at the raw water inlet and the density of water for that temperature will be used in the efficiency equation.

f. Gate Opening The gate opening is normally regulated by the governor and is dependent on head across the unit. The unit will be tested at

approximately the "on cam" position for gate opening and at at eight other openings four higher and four lower, each approximately 4% from each other except that the extreme positions will be approximately 4% from the adjacent position. Exceptions will be made if the prescribed positions cause rough running or are beyond the capability of the unit. Gate position will be verified by manually inputting head into the governor. Servomotor stroke position will be measured to 0.01 inch.

g. Method of Analyzing Data Test data will be represented graphically as efficiency versus servomotor stroke for a constant head to determine best gate position. Data from tests made over a range of heads will be shown on a graph with the X and Y coordinates representing servomotor stroke and head. Lines of constant efficiency will then be plotted. A line showing the most efficient gate opening for any head can be drawn which would represent the optimum cam profile.

6. Setting Up Test Equipment This section deals with manpower requirements, and special attention required when setting up some of the test equipment.

a. Watt Meter Counter The watt meter counter can be set up in approximately three hours by one electrician. Special care is required in positioning the electric eye and setting sensitivity so that precisely one count per revolution is made.

b. Manometer The manometer can be set up in approximately three hours by two mechanics. Some additional time is required if it is used for pump testing the Francis unit as a vacuum pump will also be required. Special care is required to be sure that there are no leaks. Any leaks that cause the inflow of additional water will adversely affect accuracy of the discharge measurements.

c. Pressure Taps The flowmeter pressure taps need to be inspected within two months of actual testing to be sure that surfaces within 18 inches

of the taps are smooth, clean, and protected. This will require unwatering of the units scroll case and the draft tube of the Francis Unit when testing in the pumping mode. Within ten days of the actual test the pressure tap lines should be flushed with compressed air.

d. Kaplan Unit Before the initial index testing, that unit should be unwatered and some measurements taken with the governor operating "on cam" at 10 percent intervals in gate opening from 0 to 100 percent. The following measurements should be made and recorded for at least three head conditions:

1. Gate opening indicated on the governor cabinet
2. Gate opening indicated on the operating ring
3. Actual wicket gate opening (average of several blades at top, bottom, and middle)
4. Actual blade angle indicated on trunion
5. Blade angle indicated on the oil head
6. Position of governor blade angle restoring cable
7. Position of cam follower
8. Head and tailwater input to governor

7. Personnel Requirements for Testing This section makes specific recommendations concerning personnel requirements for testing.

a. Pretest Meeting

Before testing begins a pretest meeting will be held with all test personnel attending. Items for discussion will be -

1. Method of communication
2. Individuals duties
3. How to make changes in procedures

4. What to do if a mistake is made

b. At the Watt meter Counter One person will be required at the watt meter counter. His/her duties will be pushing the start and end count buttons at the beginning and end of each test, reading data off the counter, calculating average unit output, and recording that information. One other person will be required to read and record voltage, amperes, and power factor.

c. At the Manometer Four people will be required at the manometer. Their duties will be bleeding the pressure tap lines and regulating water surface elevations in the manometer tubes to convenient elevations so that they can be read. Readings will be taken at 30 second intervals for five minutes. This will be accomplished by one person calling out when the readings should be taken. Then that person and each of the other three will take readings. The first person will then record that data. After the readings have been taken, recorded, averaged and checked, the average differential should be calculated and recorded.

d. At the Turbine Pit Two people will be required. Their duties will be to measure servomotor position during testing and record that measurement.

e. At the Governor During testing of the Kaplan unit two people will be required. Their duties will be to control the turbine wicket gates and to adjust the blade angle as directed by the test coordinator. They will also record information for blade angle and record and average reservoir elevation and tailwater elevation.

During testing of the Francis unit two people will be required. Their duties will be to control the turbine wicket gates and to record information for gate opening in the pumping mode. They will also record and average reservoir and tailwater elevation.

f. At the Reregulation Dam Gates During testing of the Kaplan unit and

testing of the Francis unit in the generating mode two people will be required. Their duties will be to control the gates as directed by the test coordinator to keep the tailwater at a constant elevation.

g. At the Spillway Gates During testing of the Francis unit in the pumping mode two people will be required. Their duties will be to control the gates as directed by the test coordinator to keep the tailwater at a constant elevation.

g. Test Coordinator The test coordinators duties will be to supervise and direct the personnel located at the above stations and also the plant operator so that all will be coordinated. It will also be his/her duties to coordinate activities with power system requirements and the reservoir control office and to set up a system of communication. The test coordinator will be the plant superintendent or someone appointed by him/her.

i. Technical Director The technical director's duties will be to outline test procedures, analyze test data for verification of accuracy while testing is in progress, to make recommendations of changes in test procedures as required for technical reasons. His/her duties will include spot checking of procedures used at each station to insure that the test results are adequate. The technical director will be the Omaha District's Representative.