CHAPTER 1

INTRODUCTION

1-1. PURPOSE. This manual has been prepared for use in planning and design leading to the selection and preparation of technical specifications for reaction turbines and pump-turbines, generators and generator-motors. The information included in this manual is not intended to eliminate the necessity or desirability of consulting with equipment manufacturers.

1-2. APPLICABILITY. This manual is applicable to all field operating activities having hydroelectric civil works design responsibilities.

1-3. REFERENCES.

a. CE 2201.01 HYDRAULIC TURBINES - FRANCIS TYPE

b. CE 2201.02 HYDRAULIC PUMP - TURBINES - FRANCIS TYPE

c. CE 2201.03 HYDRAULIC TURBINES - KAPLAN TYPE

d. CE 2202.01 HYDRAULIC TURBINE DRIVEN - ALTERNATING CURRENT GENERATORS

e. ANSI/IEEE Std 421.1-1986, "IEEE Standard Definitions for Excitations Systems for Synchronous Machines," available from IEEE, 345 East 47th St., NY, NY 10017.

1-4. DISCUSSION.

a. Corps of Engineers hydroelectric power plants are part of multi-purpose projects which develop power incidental to their major purposes of flood control and/or navigation. Corps projects may concurrently serve irrigation, recreation and water supply purposes.

b. Hydraulic turbines and pump-turbines are not off-the-shelf items and must be designed to suit the specific range of conditions under which they will operate. Selection of the most suitable hydraulic and electrical equipment requires careful study and investigation.

c. This manual includes procedures to be followed, model test data of reaction turbines and pump-turbines and other material useful in selecting the equipment and preparing the performance data to be included in technical specifications.

1-5. <u>PROJECT PLANNING AND FIELD SURVEY STUDIES.</u> These studies establish the following data:

a. Power capacity - dependable and rated.

b. Energy output.

c. Reservoir capacity and headwater curves.

d. Tailwater and afterbay capacity curves.

e. Minimum flow requirements.

f. Other use requirements.

g. Pumping requirements.

h. Preliminary selection of type and number of Units.

i. Heads - maximum, minimum and average.

j. Foundation conditions.

k. Special conditions under which the plant must operate.

1-6. <u>GENERAL PRINCIPLES.</u>

a. The function of a hydroelectric power plant is the conversion of potential energy (water falling over a distance or head) into mechanical energy (rotation of the turbine or pump-turbine shaft). This shaft in turn is connected to the shaft of a generator or generator-motor to convert mechanical energy into electrical energy.

b. In the pumping mode, the generator-motor drives the pump-turbine to pump water to a higher elevation so that it will be available when needed to operate the pump-turbine in the generating mode to produce electrical energy.

c. The quantity of water available for the production of power in the foot-pound-system is measured in cubic feet per second (cfs) and designated as Q. The vertical distance available is measured in feet and designated as H. The theoretical horsepower available or water horsepower (WHP) due to a quantity of water (Q) falling H feet is WQH foot pounds per second, where W is the specific weight of water in pounds per cubic feet, and the available water horsepower is:

$$WHP = \frac{w\,Q\,H}{550}$$

d. The amount of power that can be produced under practical working conditions is less than the theoretical amount. This is due to losses in the conveyance of water (including the tailrace), and the losses in the conversion equipment.

e. Conveyance losses show up as the difference between the gross head (H_g) on a plant and the net or effective head (H_e). For Francis and propeller type turbines, the net head is the difference in level between headwater and tailwater minus all frictional losses and minus the velocity head of the water in the tailrace. Friction losses occur as the water passes through the trash racks, intake, penstock and tunnel including bends, branching pipes, transitions and valves up to the entrance of the spiral case. The power delivered by the turbine to the generator is measured in horsepower (HP).

$$HP = \frac{w\,Q\,He\,Ep}{550}$$

where E_P is the efficiency of the prototype turbine. The kilowatt output of the generator is 0.746 E_G times the horsepower delivered to the generator shaft, where E_G is the efficiency of the generator.

f. In pumping, the head is the total head from suction pool to the discharge of the spiral case plus the conveyance losses, except that for Tube or Slant Axis turbines and low head vertical units with short intakes it is the pool-to-pool head.

1-7. SIZE AND NUMBER OF UNITS.

a. The capital cost per kilowatt of a hydroelectric plant of a given total capacity generally decreases as the number of units decreases. A minimum of two units is usually preferred, but in special cases one unit may be acceptable.

b. Size alone is not a determining factor in selecting the number of units to be installed. The most economical size and number of units can only be determined by a careful analysis of limitations and conditions. The following limitations, requirements and conditions must be carefully considered.

(1) Single unit plants have lower operating and maintenance costs, but service equipment, cranes, etc. will be more expensive.

(2) A new unit of larger size than any other in the system may necessitate additional system capacity.

(3) Character of the load that the plant is expected to supply and the flexibility of operation required.

(4) Requirement to supply an isolated load.

(5) Requirement to supply low flow releases.

(6) The need to install units of unequal size.

(7) Requirement for future units.

(8) Even or odd number of units. Electrical connections may dictate an even number of units.

(9) Shipping limitations (one piece runner, etc.).

(10) Foundation conditions.

(11) Requirements of the pumping cycle.

1-8. TYPES OF TURBINES. Modern hydraulic turbines may be classified as reaction turbines or impulse turbines.

a. Types of Reaction Turbines include:

(1) Francis.

(2) Fixed Blade Propeller.

(3) Adjustable Blade Propeller (Kaplan, Tube or Slant Axis, and Bulb).

(4) Fixed Blade Mixed Flow.

(5) Adjustable Blade Mixed Flow (Deriaz).

Water passages are enclosed and completely filled with water. The energy transfer from the water to the turbine runner is due to the pressure and change in direction of the water. Reaction turbines operate at heads up to 1600 feet or more. The setting, while usually vertical, may be horizontal or inclined.

b. Impulse turbines are suitable for operation at heads as high as 6000 feet. The water is open to atmosphere at all points beyond the nozzle and the transfer of energy from the water to the runner is due to the turning of the jet nearly 180 degrees by the buckets which are arranged around the periphery of the runner. The setting may be horizontal or vertical.

1-9. TYPES OF PUMP-TURBINES.

a. Pump-turbines are similar to reaction turbines, except that they operate in one direction of rotation as pumps and in the opposite direction as turbines. They consist of three principal types:

(1) Radial flow or Francis type.

(2) Mixed flow or diagonal flow.

(3) Axial flow or propeller type.

b. The mixed flow and Axial flow types include both fixed-blade and adjustable-blade machines.

1-10. MODEL TEST.

a. Hydraulic turbines and pump-turbines are not off-the-shelf items of equipment. They are designed to suit the head, power and pumping requirements of a particular site.

b. While manufacturers have models developed to cover a range in heads and capacities, modifications to an existing model or development of a new model design may be necessary to determine performance at a specified condition.

c. Model testing is necessary if the state of the art is to advance. New improved designs which permit more economical speeds, improved efficiencies and settings with relationship to tailwater need to be developed. The Corps of Engineers requires model tests to develop a runner most suitable to the requirements of the project and to confirm that the guaranteed performance will be met. As more model and prototype tests become available, more accurate results of model changes and model development can be predicted.

d. In some cases field tests are not possible to check guaranteed values of performance. In these cases, model tests are accepted as the guaranteed tests.

e. The allowable specific speed for a turbine or pump-turbine under given head conditions is dependent upon the setting with respect to tailwater, atmospheric pressure, water density and the vapor pressure of water. A manufacturer may have a family of curves for heads up to 1500 feet or more (depending on the type of turbine and the setting above or below tailwater). However, prototype tests should be made to validate his design and model tests.

f. The size of the model runner tested may vary with different manufacturers and the test results may be based on inlet, throat or discharge diameters. Corps specifications require the model runner throat diameter to be not less than 10 inches and further requires that the guaranteed model efficiency be based on a model with a runner throat diameter of 12 inches.

g. Efficiency of prototype turbines should be higher than that of models. The amount of increase to be expected will vary depending on the manufacturer and his experience. Therefore, an exact comparison of performance of two models by different manufacturers cannot be made.

1-11. <u>EVALUATION OF EFFICIENCY.</u>

a. The increase in efficiency to be expected from tests of identical models in different laboratories has been known to vary two percent.

b. The surface finish on runner and gates on a model has been known to vary the efficiency by as much as 1/2 percent.

c. Model test values can be repeated closer than 1/4 percent.

d. Manufacturing tolerances may result in a step-up between model and prototype that is different than expected.

e. Two units of the same design and identical within manufacturing tolerances, installed in the same plant have given test results differing by more than the probable error of testing.

f. For many years, european test codes as well as the International Test Code acknowledged the probability of error in instrumentation by a tolerance for output and efficiency of ± two percent. Guarantees of 92 percent are considered to be met if final computations of field test results showed 90 to 94 percent. The United States Test Code (ASME) does not provide any tolerance on guarantees and this has resulted in the lowering of guaranteed values by american manufacturers. These guaranteed values, depending on the size of the unit, have varied from 90 to 92 percent.

g. In a known case where high efficiencies were guaranteed with large penalties for not meeting guarantees included in the contract, a two percent decrease in efficiency was equivalent to more than half of the contract price.

h. Specifying too high an efficiency can result in excessively high bid prices.

i. Model tests are used as a means of providing the unit best suited for a particular project. The Corps specifies minimum efficiencies to be met for both model and prototype at specified outputs when field tests are to be made and only model efficiencies when field tests are not to be made.

j. Efficiencies are not evaluated in the comparison of bids. However, penalties for failure of the prototype to meet guarantees are included in the specifications.

1-12. DATA ON UNITS INSTALLED IN CORPS OF ENGINEERS PLANTS. Data on units of equipment installed in Corps of Engineer's Hydroelectric Plants is included in Appendix B. This data will be of assistance in selecting equipment, but it must be recognized that considerable improvement in design and performance has been made on some units in recent years and that foundation conditions may have imposed restrictions on selecting the speed and size of a unit, and the depth of the draft setting.