Electrical Design of Pumping Stations

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Chapter 10
Pump Drive Selection

10-1. General

Several options are available to the designer when considering the selection of a pump drive for flood-protection pumping stations. The two factors that must be investigated when making this selection are reliability and cost. Alternative studies should be made considering these two factors. The two types of drives to be considered are electric motors and internal combustion engines. Gear drives are required as part of the drive system when using engines. Gear drives can also be used with electric motors permitting the use of a less expensive higher speed motor and allowing a greater variation in the pump speed than permitted with direct drive.

10-2. Reliability

The primary consideration in the selection of any pump drive is reliability under the worst conditions likely to prevail during the time the station will be required to operate. The reliability of the electrical power source should be determined from power company records of power outages in that area and their capability to repair any outages. Consideration of power from two different power grids within a company may be advisable for large pumping stations. The reliability of the various types of equipment must also be studied. Electric motors and engines are usually very reliable while the necessary accessories to operate these units are less reliable. The complexity of operating and repairing the piece of equipment by the operating personnel should also be considered. Equipment repair requiring specialized service personnel may require much greater time to put it back into service.

10-3. Cost Considerations

a. General. Unless reliability considerations are important enough to decide what type of drive to use, annual cost comparisons should be made of all systems under study. The annual costs should include the installed, operating, maintenance and replacement costs. After all costs have been established, a life-cycle cost analysis can be performed.

b. Installed costs. The installed costs include the construction costs of all the equipment and the electric power supply costs, which usually would include the cost of the substation plus the power line to the station. These costs should be figured out on an annualized basis using the number of years determined for the project's life.

c. Operating costs. The operating costs would include the cost for energy and manpower expenses. To accurately estimate the total energy costs, an estimate of the amount of pumping required for each month of the year must be obtained. The source of pumping time should be obtained from hydrology period-of-record routing studies. The current price schedule for electric power from the supplying utility or the market price of engine fuel can be used to determine the costs for all stations except for large stations. For large stations, a study of future energy costs over the life of the project is justified. In determining the total cost of electricity, it is important to include the cost for the energy used (kilowatt hours) plus any demand (capacity) charges. Demand charges by some power companies may be a major part of the energy costs.

d. Maintenance costs. Maintenance costs include manpower and materials for both preventative and major repairs. Unless the station has specialized equipment, these costs are usually estimated using the following percentages of the installed equipment costs:

Station Size	Percentage (%)
25 ℓ/s (1.0 cfs)	0.5
15 m^3/s (530 cfs)	5.0

Percentages for intermediate station sizes are determined proportionally with the above values. The maintenance cost of unusual or specialized equipment would be measured separately and would be an additional amount.

e. Rehabilitation and replacement costs. Rehabilitation and replacement costs include those costs required to keep the station operable for the project life. For a normal 50-year station life, most of the equipment would be rehabilitated or replaced at least once, except for very large pumping stations. The periods between the rehabilitation/replacement could be shorter if the operating time were great. Major items such as pumps, drivers, and switchgear are figured to be rehabilitated or replaced once during the 50-year life. This major equipment rehabilitation or replacement is usually estimated to occur between 20 and 40 years after placing the station into operation. Rehabilitation costs for major equipment can be estimated to be 35 to 45 percent of replacement costs depending on the condition of the equipment. Other items of equipment may be replaced several times during the project life depending on their use or may require only partial replacement. It is most likely that equipment, except for the pump and motor, may not be replaced in kind. Therefore, the replacement cost should include all engineering and structural modification costs as well as the equipment costs. In any event, the equipment removal costs including the cost of all rental equipment plus the installation cost of all new equipment should be included.

Chapter 11
Pump and Station Hydraulic Tests

11-1. General

Two types of tests are generally performed in connection with a pumping station and its pumping equipment before the station is built. Tests are run on pumps, either full size or model, to determine their performance and to demonstrate that the performance of the pump complies with specification requirements. Physical hydraulic model tests of the pumping station substructure may also be conducted to assess its hydraulic performance.

11-2. Pump Tests

a. General. The pump performance tests are conducted at the pump manufacturer's facility. Field testing to prove performance at the completed station is more difficult and costly if not impossible in many cases. All pumps should be factory tested to determine their capacity, total head, efficiency, and horsepower requirements. Pumps normally should also have a cavitation test performed. This test is usually performed on a model. Model testing specifications and parameters can be found in Guide Specification CW 15160, Vertical Pumps, Axial and Mixed Flow Impeller Type.

b. Description. Factory pump tests are either performed on full-size pumps or performed on a model pump of the full-size pump. If a model pump is used, it should be geometrically like that of the full-size pump and of the same specific speed. Either type of test is acceptable to check the ratings of the pump; however, because of size limitations, most manufacturers limit full-size tests to pumps of less than 2 m^3/s (75 cfs) capacity. A pump test consists of determining the total head, efficiency, and brake horsepower for a range of capacities. All testing should be witnessed by the district office design personnel performing the station design. The dimensions of the model and prototype impellers should be made by using drawings, measurements, and scaling factors. The performance factors measured include capacity, pressure head, horsepower, and suction pressure when cavitation performance is to be determined.

c. Performance tests. All pumps for flood-control pumping stations should have their performance verified by tests. For installation of identical pumps in a station, only one of the pumps needs to be tested. Tests on similar pumps used for another station will not be acceptable as equivalent tests. The test setup should permit, and the specifications require, the pump to be tested over a range of heads starting at least 600 millimeters (2 feet) greater than the highest total head requirement or at shut-off and extending down to the lowest head permitted by the test setup. The test should, if an unstable range ("dog leg" in the head curve) exists. Sufficient test points should be run to adequately define the unstable range. This allows the pump manufacturer to demonstrate that their pump does not operate in the unstable range. The lowest head tested should be at least equal to the total head that occurs for 95 percent of the operation time during low head pumping conditions. For pumps with capacities greater than 11 m^3/s (400 cfs), the model tests should be required to cover the complete head range required by the specifications including down to the lowest total head specified. All performance tests should be run at the same head at which the pumps will operate during actual duty. The readings of capacity and brake horsepower along with the total head will be used to determine the pump efficiency. For model tests, no correction factor for efficiency due to size differences will be allowed. Tests will be performed at water levels like those which will occur during actual operating conditions. An actual scale model of the station's inlet and discharge systems is not warranted except for pumps over 14 m^3/s (500 cfs). This requirement should also be used when the sump is not designed by the Government and is a part of the pump contract or has some complicated flow passage which has not had a sump model test. The pump test is used to ascertain the performance of the pumps, not how it reacts in the prototype sump except in the cases listed below. It is expected that the factory sump would be free of vortexes and adverse flows so that good results are obtained. Manufacturers are responsible for furnishing a pump that conforms to the specifications and meets the performance in the sump to be provided by the Government. The pump manufacturer should be held responsible for poor sump design, evidenced by vortexing and bad flow conditions within the sump, when the contract specifications require the sump to be designed by the pump manufacturer. Except for this special case, the pump manufacturer warrants performance of the pumps only, not the sump, and the activity within the sump would be the responsibility of the Government. Duplicate model pump sumps should include the sump from the inside of the trash rack. Any pump using a formed suction intake should be tested with this formed suction intake. Vertical pumps should be tested only in the vertical position.

d. Cavitation tests. Cavitation tests are performed to indicate the operating conditions in which the pump will start cavitating. For purposes of design, it is assumed that cavitation starts when the pump performance starts to decrease as the effective sump level is reduced. The inception of cavitation definition has not been agreed upon by all the pump suppliers and users. A typical pump test consists of operating the pump at a fixed capacity while reducing the pressure on the suction side of the pump. As the suction pressure is reduced, a point is reached where a plot of the head-capacity curves deviates from a straight line. The Corps specifies the start of cavitation at a point where the curve starts to deviate from the straight line. Others use as the start of cavitation, a point where a 1- or 3-percent deviation in performance from the straight line occurs. Submergence requirements, as used in this course, are based on the Corps criterion of zero deviations from the straight line portion. In most cases, some cavitation has already started at either point; therefore, a design allowance of extra submergence should be provided in addition to that indicated by the tests results. The submergence allowance is based on the estimated number of operating hours expected annually. The amounts of allowance are indicated in Appendix B. In all cases, the cavitation tests should be performed in a test setup that uses a variation of water levels on the suction side of the pump.

11-3. Station Tests

a. General. Hydraulic model tests of pumping station sumps and discharge systems should be performed by WES for stations with unique or unusual layouts. The procedure in ER 1110-2-1403 should be followed when requesting model tests. A decision should be made on the requirement for model testing during the General Design Memorandum stage so that the results of any testing are available during the design of the station. Test results are usually not available until 6 to 9 months after forwarding a work order to the test agency.

b. Sump model tests. The primary purpose for performing a model test of a pumping station sump is to develop a sump design that is free of adverse flow distribution to the pump. Optimal flow into a pump impeller should be uniform without any swirl and have a steady, evenly distributed flow across the impeller entrance. However, it is usually not possible to obtain the optimal flow conditions without considerable added expense. Acceptable pump operation will occur when a deviation in the ratio of the average measured velocity to the average computed velocity is 10 percent or less and when the swirl angle is 3 degrees or less. Swirl in the pump column is indicated by a vortimeter (freewheeling propeller with zero pitch blade) located inside the column. Swirl angle is defined as the arc tangent of the ratio of the blade speed at the tip of the vortimeter blade to the average velocity for the cross section of the pump column. There should not be any vortex formations allowing entrance of air into the pump. In order to accurately simulate the field conditions, the model should include sufficient distance upstream of the station to a location where changes in geometry will not affect flow conditions in the sump. The prototype-to-model ratio is usually determined by the testing agency, but it should not be so large that adverse conditions cannot be readily observed. Normally the model should be sized to ensure that the Reynold's number in the model pump column is equal to or exceeds a value of 1×10^5. Reynold's number is defined by the following equation:

$$R = dV/r \qquad (11\text{-}1)$$

where

R = Reynold's number
d = column diameter
V = velocity
r = viscosity of water

c. Discharge model tests.

(1) General. These tests are performed to evaluate the performance of a discharge system. Usually, two types of systems are investigated, discharges which form a siphon and/or through the protection discharges for large stations where the friction head loss would be a substantial portion of the total head of the pump.

(2) Siphon tests. The siphon tests are run to determine that a siphon will prime the system in the required time. This test is recommended when the down leg of the siphon system is long, or it contains irregular flow lines and for pumps of 20 m^3/s (750 cfs) or greater having a siphon built into the station structure.

(3) Discharge tests. A head loss test should be considered only for pump discharges with capacities of 20 m^3/s (750 cfs) or greater and where the accuracy deviation for estimating the total head exceeds 20 percent of the total head. Other considerations would be the size of the pump and its driver. In some cases, a safety factor of 10 to 20 percent of the total head may not change the pump unit selection, and therefore the expense of a discharge test may not be warranted. For those stations where the size of the driver is close to its rating, a test may be in order to ensure that the driver would not be overloaded due to error in head determination.

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