INTAKES AND OUTLETS FOR LOW-HEAD HYDROPOWER

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This paper presents the results of a state-of-the-art review performed to investigate the present status of standardization of flow passage design for low-head hydropower developments. The current design practices regarding flow passages are summarized and examined to determine if improvements could be made to reduce losses or simplify present design without introducing significant additional losses.

The objective of standardization is to reduce the cost of low-head hydropower. The main purpose of this phase of the study was to determine the present status of standardization of flow passages and to determine if standardization is a feasible means of reducing the cost of low-head structures. Another objective was to examine current design practices to identify areas where design changes or further research could result in less costly structures.

The need for additional energy production combined with diminishing reserves of fossil fuels has resulted in a need to develop the remaining hydropower capacity in the United States. There are many existing impoundments and completely undeveloped sites that could be developed with little effect on the environment. There are also many sites in need of updating. Additional generating units and replacement of obsolete equipment could significantly increase power generation from these sites. At the same time, coal-fired and nuclear powerplants face an uncertain future because of environmental concerns and lengthy licensing procedures. Low-head hydropower could make a substantial contribution to help gap the predicted energy shortage in the next 10 years.

The main obstacle to development of low-head sites (heads below 20 m) has been economics. The cost of energy generated with low-head hydropower is still slightly higher than with fossil fuel plants. However, with the cost of fuels continuing to rise, the low-head hydropower alternative is becoming more favorable.

In low-head plants, the head losses could reduce the net effective head by a significant portion of the total available energy. Therefore, it would be desirable to streamline the flow passages as much as possible to minimize the head losses. At the same time, economics dictates that the flow passage shape be as simple as possible. With these conflicting interests in mind, the present design methods were examined to determine possible design improvements to further reduce losses or to simplify present designs without introducing additional losses.

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The design of penstock entrances for high-head dams is one example that illustrates the value of taking a closer look at conventional design practices. It was conservatively estimated that $13 million was saved in construction costs on the penstock entrances for the Third Powerplant at Grand Coulee by reducing the size of the bellmouth entrances. Penstock entrances had historically been designed using the same criteria used in designing high-velocity conduits, while the velocity in penstocks is much lower. Hydraulic model studies indicated that losses were actually lower in the smaller entrance. The same criteria used to design high-velocity conduits are used to design intake shapes for low-head plants. Therefore, savings may be possible by changing design methods in low-head structures.

The work during the first year of this study included a literature review and contacts with manufacturers, consultants, and operators of low-head turbines.

The flow passage studies included:

1. The forebay - which controls the flow approaching the intake
2. The intake - which accelerates the flow to the turbine
3. The draft tube - which decelerates the flow to recover the kinetic energy
4. The tailrace - which carries the flow away from the turbines

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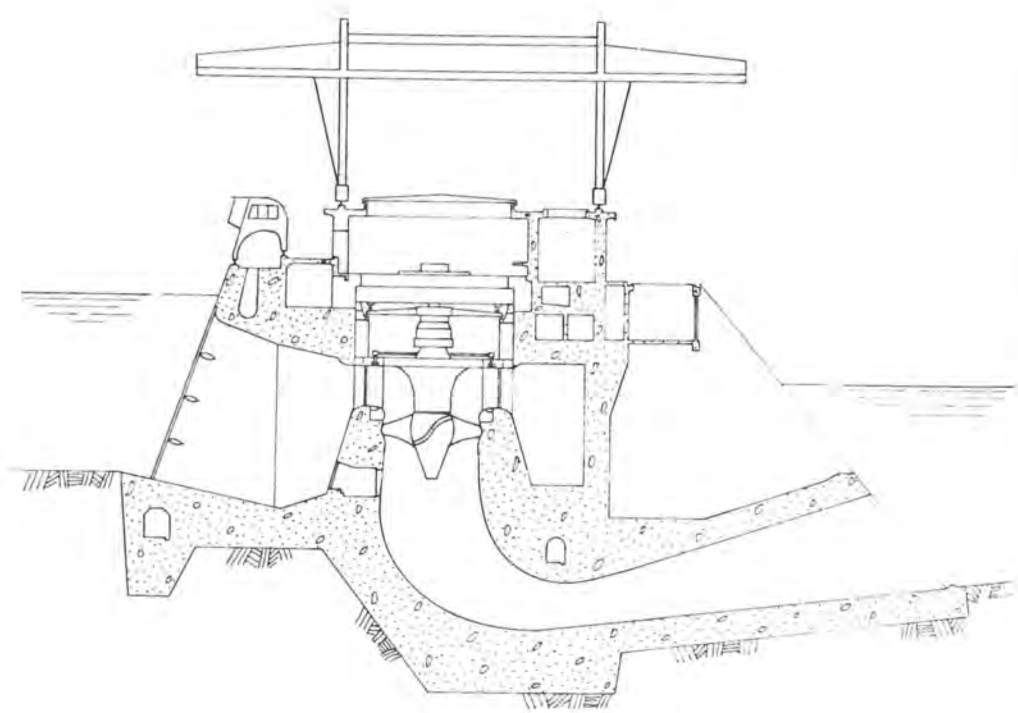
Kaplan Turbines

In the head range between 3 and 45 m, turbines with propeller-type runners are typically used. If the runners are adjustable, the turbines are called "Kaplan turbines." These turbines are usually arranged with a vertical shaft, a spiral case, and an elbow-type draft tube. A large percentage of present low-head turbines are this type. However, at heads less than 20 m, axial flow turbines have proved to be more economical. This study is mainly concerned with the low-head range, less than 20 m, although some material on small high-head turbines is also included.



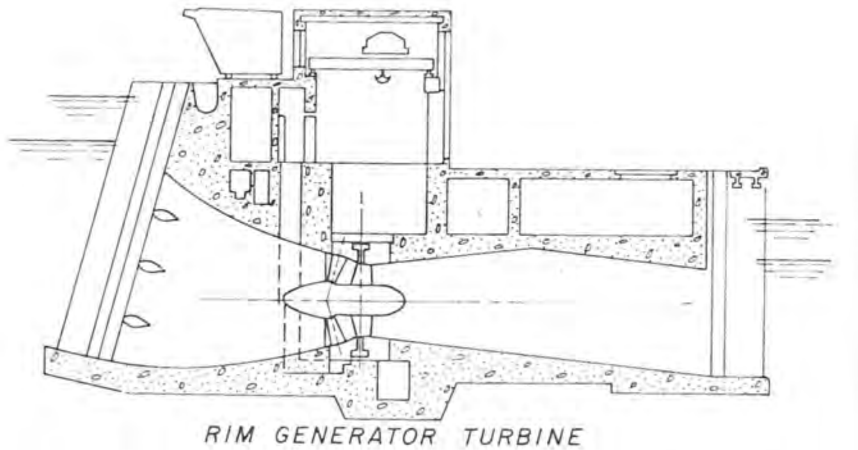
VERTICAL KAPLAN TURBINE

ESCHER WYSS

Axial Flow Turbines

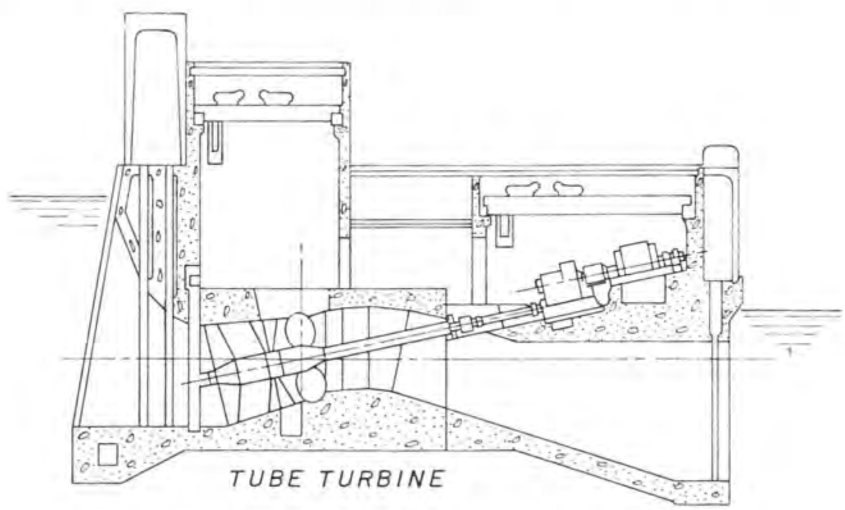
Turbines in which the water is conducted to the distributor coaxially with the shaft are called "axial flow turbines" or sometimes "tubular turbines." To avoid confusion, the term "axial flow turbine" is used in this report. Axial flow turbines also use propeller-type runners. In some cases, adjustable (Kaplan) runners are used. The three primary types of axial flow units are described in the following paragraphs: (1) the rim-generator turbine, (2) the tube turbine, and (3) the bulb turbine.

1. Rim-generator turbine. - The first axial flow unit, the rim-generator, was invented in 1919 by L. F. Harza. The generator is attached to the periphery of the runner and lies outside of the water passage.



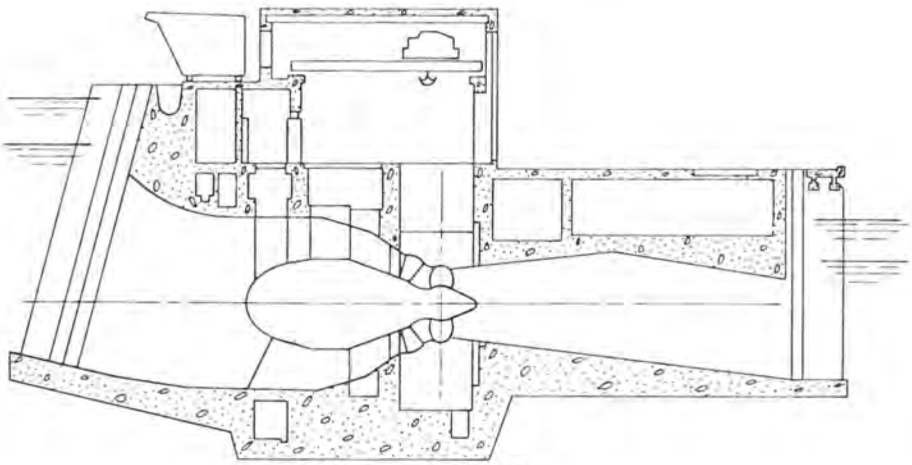
RIM GENERATOR TURBINE

2. Tube turbines. - In 1930, the tube turbine was patented. This design was used mainly in Europe for small installations. In 1960, this idea was reactivated in the United States at Ozark Lock and Dam on the Arkansas River. In this design, the generator is driven by a long upstream or downstream shaft.



TUBE TURBINE

3. Bulb turbine. - In 1933, the bulb turbine was patented. In this arrangement, the generator and turbine are encased inside a shell within the water passage.



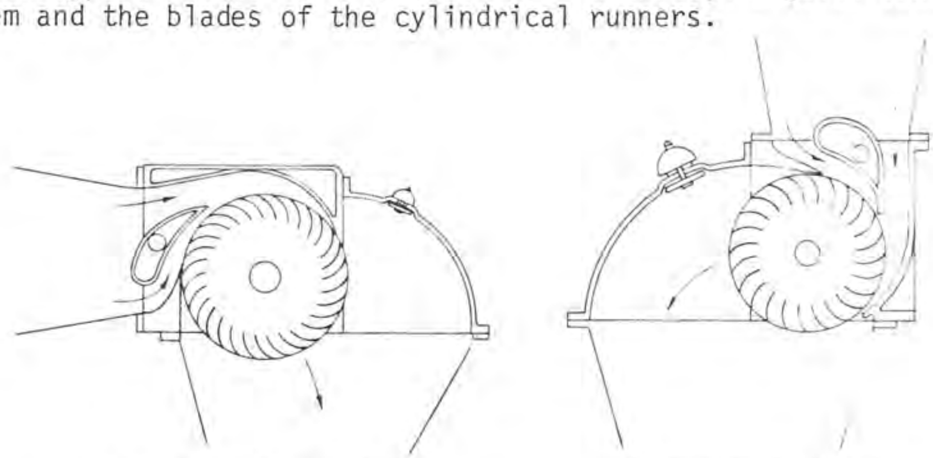
BULB TURBINE

Standard "Off the Shelf" Units

A few package-type turbine and generator units are available in the low-head range (less than 20 m). These predesigned units reduce equipment costs by eliminating the need for site-specific engineering and by using standardized manufacturing techniques. However, the standard flow passage shapes may result in a loss of turbine efficiency. These units have either fixed runner blades or fixed wicket gate positions or both, resulting in less operational flexibility. The economics of each potential site should be evaluated to determine if the savings obtained with "off the shelf" units outweigh the losses. The following standardized units are presently available:

Cross Flow Turbines

Ossberger "cross flow" turbine assemblies are available in a range of units which have the ability to cope with variations in head and discharge on small dams. The cross flow turbine is a radial impulse-type turbine. The water is forced through a guide vane system and the blades of the cylindrical runners.



HORIZONTAL ADMISSION VERTICAL ADMISSION

OSSBERGER CROSS-FLOW TURBINE

Tube Turbines

Allis-Chalmers tube turbine units. - Ten standardized packaged designs are available. Single units have capacities to 5000 kW at heads up to 15 m. Flow is controlled with a butterfly valve in the intake. The wicket gates are fixed and the runners are either fixed or adjustable.

Karlstads Mekaniska Werkstad (KMW) miniturbines. - These units are available for horizontal or vertical installation for flows from 1 to 15 m^3/s and heads from 4 to 25 m. Outputs range from 100 to 1800 kW. The turbines have fixed guide vanes and fixed runner blades, although the position of the latter can be changed when the turbine is stationary. Flow is controlled with a butterfly valve.

Bulb Turbines

Fuji package-type bulb turbine and generator. - Available in 19 models covering a range of net heads from 5 to 18 m and outputs from 300 to 4000 kW. The runner is of the fixed blade type and the flow is controlled with movable wicket gates.

Standard Dimensions

A few manufacturers provide drawings with standard flow passage dimensions. These dimensions were determined as a result of model tests and their operational experience over a period of years.

At this time there are no universally accepted flow passage shapes. Studies on optimization of flow passage shapes done by manufacturers are considered proprietary information. Therefore, the effect of simplifying intake and exit shapes on hydraulic losses is not well known. The shape of the flow passage is generally determined by the manufacturer and the standard design varies widely among manufacturers.

Standard Designs for a Line of Turbines

An alternative to standardization of flow passages in general would be to develop a standardized design for a series of powerplants to be installed at similar locations. A feasibility study was performed by Motor-Columbus Consulting Engineers to investigate harnessing of the Rhine River upstream of Lake Constance. The study investigated using 46 standard bulb units in 16 stations. This concept may be applicable to development of low-head power on American rivers with several possible low-head sites, such as the Ohio or Mississippi Rivers where numerous navigation dams without power generation currently exist. A standard design would reduce the costs associated with site-specific engineering for each powerplant.

Mini Power Stations in Sweden

The Swedish Power Association has initiated a program to overhaul and replace discontinued small power stations (100-1500 kW) in Sweden. Pilot stations indicated that it was difficult to bring the costs down enough to make the units economically profitable. However, the Swedish Government has made economic aid available (up to 35 percent of the cost) for the least profitable projects. Economic aid was considered to be justified since hydropower reduces dependence on imported oil and is a renewable, environmentally acceptable form of energy that would otherwise be wasted.

Comments on Standardization

Most designers and consultants contacted felt that standardization of the inlet and outlet sections for low-head hydropower installations will not always bring the optimum solution. The shape of the water passage is influenced by the structural support system requirements and the geology of the site. Even units designed by the same manufacturer vary from project to project. However, the need for a manual to serve as a guide and promote standardization of flow passage designs was considered to be a worthwhile objective. While not all designs would be exactly the same, a manual would bring together information contained in scattered sources and aid in the planning and design process.

Current Design Practices

Material in technical literature and comments made by manufacturers and designers concerning flow passage design are discussed. The hydraulic design of the draft tube is generally done by the manufacturer since it is considered an integral part of the turbine in determining turbine efficiency. The design of the other flow passages is considered part of the overall plant design. However, manufacturers of standard designs usually control the design of the other passages also.

Information on the design of the following parameters is included:

- Forebay
- Intake - vortex formation, pier design, trashrack design, intake shape, and fish passage allowances
- Runner diameter and turbine setting
- Draft tube
- Tailrace

The area where improvement would be most significant in reducing costs would be the draft tube since the draft tube accounts for about 30 percent of the cost of the civil works in a low-head structure. Boundary layer control methods may be useful in shortening the length of the draft tube while maintaining hydraulic efficiency. Design changes in the intake and tailrace may also lead to reduced costs; however, economic benefits resulting from changes in these areas need further evaluation.

It was recommended that design changes in the intake and draft tube be further investigated in a hydraulic model and that a design manual should be prepared to aid in the design of intake and exit structures for various types of low-head turbines under various operating conditions.