Pumps as hydraulic turbines for small-scale hydropower

Waterpower is making a "comeback." After serving as a prime power source for centuries, it was phased out in favor of steam. By the 1960's, as every expert predicted a nuclear-fueled future, development of hydropower sites had come to a virtual standstill.

But suddenly, things have changed. Inexpensive oil is scarce. Nuclear power is a "no-no." On top of this comes the scare that continued use of fossil fuel is creating a "greenhouse" effect of carbon dioxide around the earth that will heat up the atmosphere and cause catastrophic weather changes.

Waterpower looks very attractive again. It is, however, a new kind of waterpower—small-scale hydro. It includes tapping relatively small streams and such unfamiliar power sources as irrigation canals, aqueducts, water injection lines, treated wastewater discharge lines, and even crude oil lines. Anywhere liquids are flowing from one level to another or undergoing a pressure reduction, there exists the potential for power recovery.

This creates a need for small hydroturbines. Many developers have turned to pumps, operating in reverse as hydraulic turbines, to satisfy their requirements. This article offers guidelines for the application of pumps as turbines. It also describes specific installations where pumps as turbines have been successfully operating.

Pumps as turbines actually have many advantages for the small power producer. Pumps are readily available, and many sizes are stock items. Pumps are essentially fixed geometry turbines and are simpler to operate and maintain since they do not have adjustable wicket gates or variable pitch runners. Pumps are extremely flexible—available configurations include wet-pit, dry-pit, horizontal, vertical, end-suction, double-suction, and single- or multistage, to mention a few. Because of the universe of pumping equipment already installed and in service, repair parts are usually readily obtainable. The first cost of a pump/turbine and generator can be as little as one half of the cost of a small conventional hydraulic turbine.

Pumps must be specifically designed for operation as turbines

Figure 1 shows typical performance characteristics of a centrifugal pump with the superimposed performance of the same pump operating as a turbine. Note that the head applied at the best efficiency point (b.e.p.) of the turbine is considerably higher than at the pump b.e.p., and the turbine head continues to increase past the b.e.p. In many instances, the standard pressure rating of the pump casing is not suitable for these increased heads, and special materials may be required to strengthen the casing. Many reverse-operating pumps are applied in pipelines as pressure-reducing devices. The downstream pressure on the exhaust side of these turbines may be very high, further increasing the pressure on the turbine casing.

Note also from Figure 1 that the flow is considerably higher for the turbine than for the comparable pump. This flow increase, combined with the increased head, results in considerably increased power output compared to the power input required by the pump. Most pump shafts are not designed to accommodate the torque associated with this increased power and, as a result, must be redesigned with special materials or larger shafts.

Runaway speed is also an important design consideration when applying a pump as a turbine. In Figure 2 it can be seen that the speed at runaway may be as much as twice the speed at the b.e.p. of the turbine, which is normally the same as the operating speed of a pump. In some cases, the bearings used in the pump may not be suitable for these high speeds and may have to be redesigned.

These considerations make it very important that pumps selected to operate as turbines be given a careful design review by the manufacturer to insure that they are suitable for the application. Purchasing a pump for use as a turbine without considering these implications could prove catastrophic later.

The use of pumps operating as turbines falls into three general categories:

(1) Drivers for other rotating equipment.
(2) Pipeline pressure reduction where electrical production is a by-product.
(3) Power generation for the purpose of producing a profit.

Pumps as drivers

The Croton Reservoir project is an example of a pump used as a turbine to drive another pump. It was completed in 1950 for the purpose of pumping water into the Delaware Aqueduct, which supplies drinking water for the City of New York. Worthington modified a 36-inch pump to be operated in reverse to drive another 36-inch pump. The pump selected for this project was a horizontally split-case type with double-suction impeller. When operating in reverse as a turbine, the discharge is through the bottom which allows the exhaust from the turbine to flow directly into the tailwater with the draft tube directly connected for a simple,

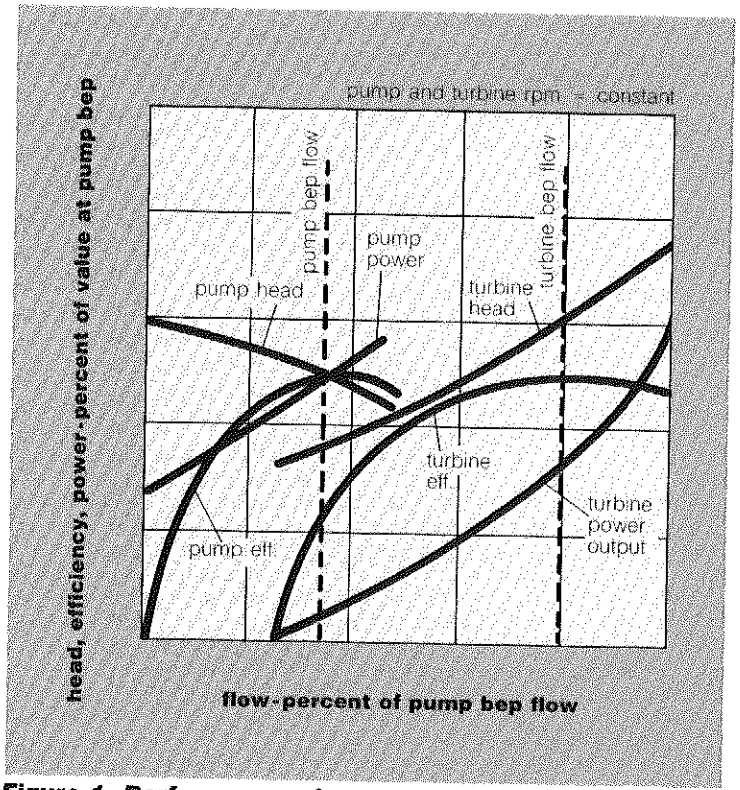


Figure 1 - Performance of pump and hydroturbine.

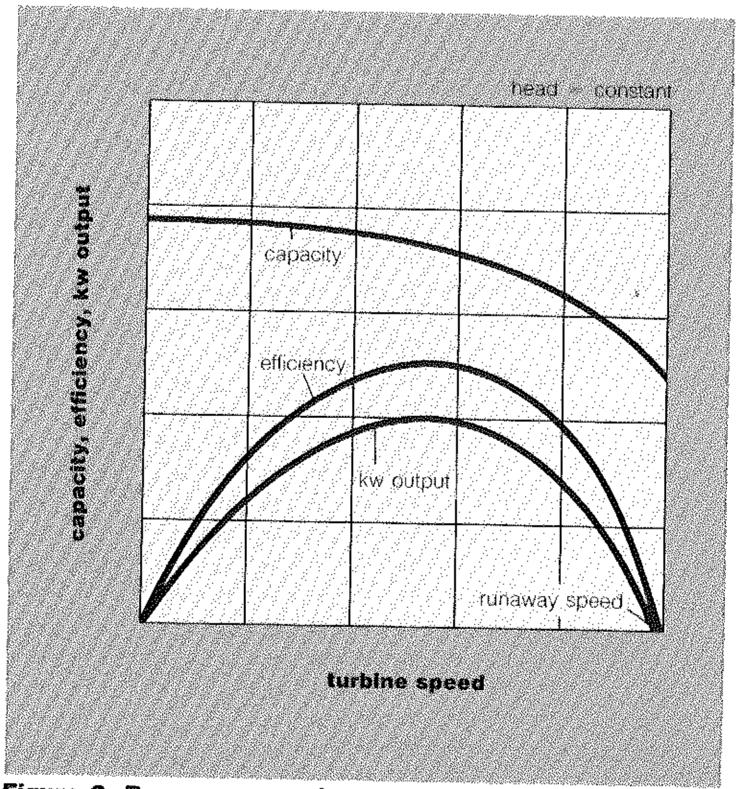


Figure 2 - Runaway speed and b.e.p.

compact installation. The conditions of service for the turbine are 114 CFS at 90 feet of head, 412 RPM producing 700 kw. The pump, operating as a turbine, in its over 30 years of service, has continued to operate smoothly and quietly and has required only recently a change of bearings, without any other major repairs.

A second example of an installation where a pump was used as a turbine to drive another pump is the Orchard Mesa Irrigation Project, installed near Grand Junction, Colorado, for the Bureau of Reclamation. The units, manufactured by Worthington, have been in continuous operation since 1926. The purpose of the project was to provide irrigation water for nearby fruit orchards on the arid western slopes of the Rocky Mountains. Water is diverted from the Colorado River upstream of the plant and delivered to the pumps and turbines via a canal and penstock. The pumps, mounted "upside down" on top of the turbines in a vertical shaft configuration, take suction water from the same penstock which feeds the intake to the turbines. After flowing through the turbine, the water is exhausted downward through a draft tube into the tailwater, which then flows back into the Colorado River.

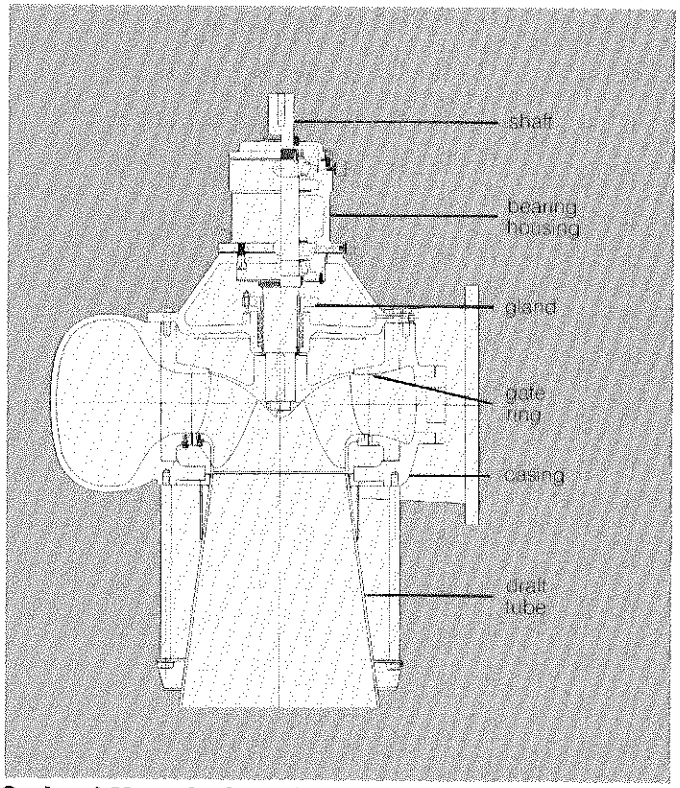
There are four existing pump/turbine units at the Orchard Mesa Pumping Plant. Two of the units are rated 76 CFS at a head of 74 feet, producing 400 kw at 535 RPM, while the other two units are rated at 31 CFS at a head of 74 feet, producing 165 kw at 480 RPM.

In 1982, after more than 60 years of operation, the decision was made to replace the existing equipment with new, modern pumps and turbines. Worthington was again awarded with the contract to supply the pumps and turbines which are scheduled for delivery by the end of 1983. Major design changes in the new units include modern anti-friction bearings instead of sleeve bearings, electronic controls instead of gauges and handwheels, and increased pumping capability. The hydraulic turbines will be in the same vertical configuration. They will be Worthington-type MNZT pumps specifically modified with fixed wicket gates for high efficiency, draft tubes directly connected to the turbine casing, and special abrasion-resistant stainless steel runners.

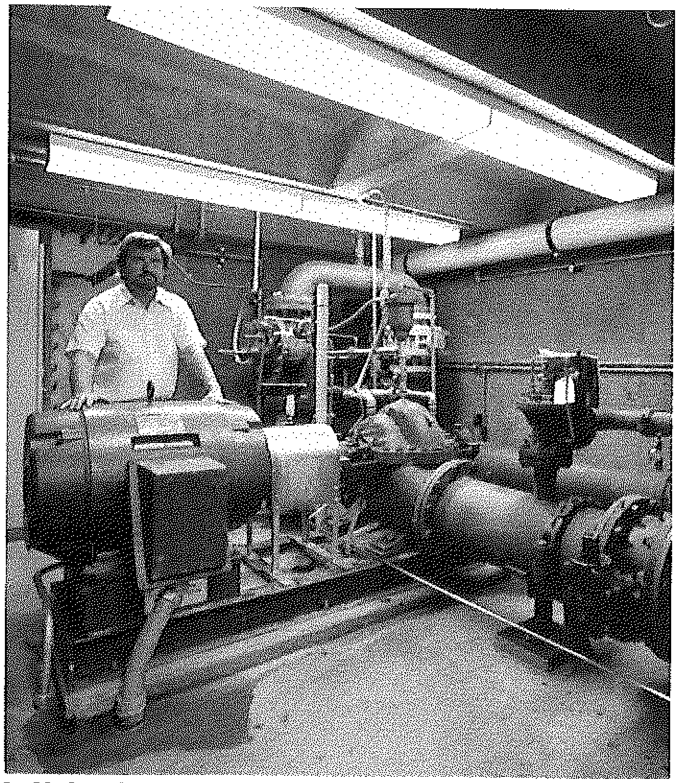
Turbine replaces pressure-reduction valve

In 1981, the City of LaHabra, California, decided to purchase a pump for reverse operation as a hydraulic turbine. The turbine would be used in the municipal water supply system of the city, in parallel with an existing pressure-reducing valve. The turbine is a Worthington Model 8LNT-12 rated 7.5 CFS at 170 feet of head with a net output of 112 kw. The primary purpose of the station, as designed by Boyle Engineering, is to reduce the pressure of the water as it comes off of the main pipeline of the Municipal Water Supply District. Production of electricity was a by-product; the system had to be designed so that water supply to the city would not be disturbed with the addition of the turbine.

The system head curve shown in Figure 2 represents how the station operates. The head is basically constant, but the flow can vary widely, depending on the water requirements of the city's residents. A pump operating in reverse is essentially a fixed geometry turbine and can only intersect the system head curve at the rated point. In order to operate at flows less than 7.5 CFS, a valve is placed in series with the turbine to break down the difference in head between the system curve and the turbine curve and the particular flow required. If flows required are greater than 7.5 CFS, the existing pressure-reducing valve, which was installed in parallel with the turbine, is opened to bypass flow as required. Thus, the



Orchard Mesa hydroturbine as pump drive.



LaHabra hydroturbine as pressure-reducing valve.

entire flow range can be accommodated.

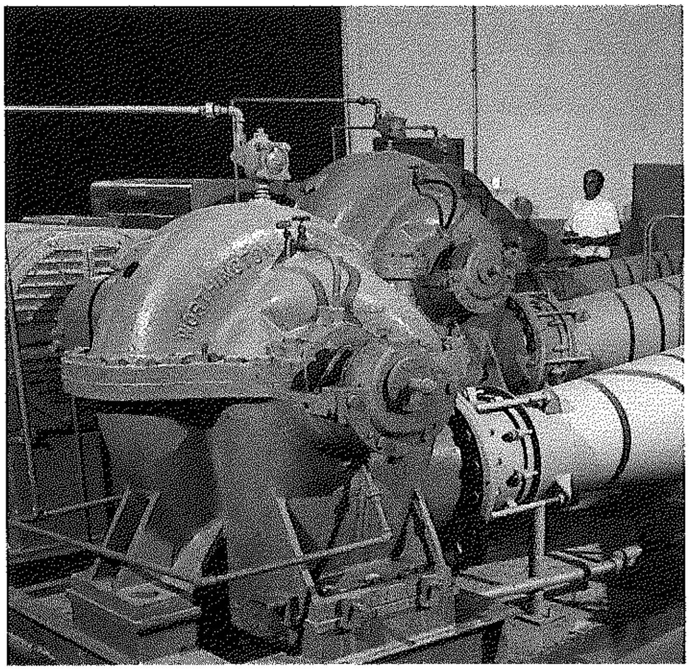
The cost to the city for the entire project was approximately $160,000. It is expected to produce about 760,000 kilowatt-hours of electricity per year, or enough to serve 125 homes. The cost is expected to be recovered within 3½ years, after which revenue from the project over the next 20 years is expected to surpass $1 million.

The pump selected had several important modifications to make it suitable for installation as a turbine. First, since the downstream water pressure was approximately 40 percent higher than the normal casing pressure of the pump, a special ductile iron material was selected for the casting. The shaft was made from high-strength stainless steel, and special bearings were selected for the high runaway speed. The turbine was started up in July of 1982 and has been operating well to date.

Pump-turbines in power stations

Projects utilizing pumps as turbines for the sole purpose of electrical production in order to return a profit to investors offer the widest applications for these machines. Following are two examples: a small, privately built project by George Butler in Jackson, Vermont; and a large, investor-financed and constructed project by Cogèneration, Inc., in Idaho.

George Butler (Butler, J. George; "How to build and operate your own small hydroelectric plant";Tab Books, Inc., Blue Ridge Summit, PA 17214; c. 1982) decided to get into the hydro business in 1976 with the help of Dr. R. Stevens Kleinschmidt. Mr. Butler built a small dam across a stream on his farm to divert the flow through a pipeline 2700 feet long to a powerhouse he built near his home. A Worthington Model 3LRT-10 pump was selected for the turbine. The turbine is connected to an induction generator through a belt drive and is rated for .7 CFS at



2MW installation at Rock Creek.

220 feet of head to produce approximately 10 kw. In 1982, Worthington supplied Mr. Butler with a second unit, a model rated at .5 CFS to be utilized during periods of low-stream flow, or in conjunction with the .7-CFS unit at periods of very high flow. According to Mr. Butler, this "do-it-yourself" installation should pay for itself in less than five years.

The Rock Creek Hydroelectric Project is a prime example of pumps used as turbines for power generation to provide a substantial return to investors. Water for the hydro project, located near Twin Falls, Idaho, is diverted from Rock Creek into a canal for 3,640 feet and a penstock for 1,580 feet. After flowing through the turbines, the water is returned to the Snake River. Four turbines operate in parallel at a net head of 170 feet with the following characteristics:

Turbine No.	Worthington Model No.	Flow, CFS	Speed, RPM	Approx. kw Output
1	20LNCT-28	58	726	680
2	20LNCT-28	58	726	680
3	16LNCT-23	36	910	420
4	14LNCT-24	23	910	265
Total Project		175		2,045

The pumps selected as turbines for this project were the horizontal split-case type. The turbines discharged straight down into the tailwater with a draft tube directly connected to the turbine outlet, providing a neat, compact installation. The induction generator is directly connected to the turbine and mounted on a common baseplate. Because of the severe climate and possibility of freezing, the casings were provided with solenoid-operated drains to evacuate all water from the turbines when shut down. Vibration detectors and other monitors were mounted on the turbines to indicate any possible problems which may occur during operation.

J-U-B Engineers, who designed the plant, also designed an automatic control system which turns each turbine on or off, depending on the available flow. By varying the operation of the units in this manner, it is possible to cover the flow-duration curve almost as well as a conventional turbine with adjustable geometry.

Conclusion

The use of pumps operating in reverse as hydraulic turbines has proven itself as a viable alternative to conventional turbine machinery. Developers are encouraged to select only pumps which have been reviewed by the manufacturer to verify that they are suitable for the application. The manufacturer, through his previous experience in the use of pumps as turbines, may also be able to offer advice and suggestions on site layout, operation, and number of units for optimal energy recovery. The flexibility of pumps operating as turbines will certainly encourage creative engineering designs on the part of both developers and equipment suppliers, resulting in new application schemes for these versatile machines.