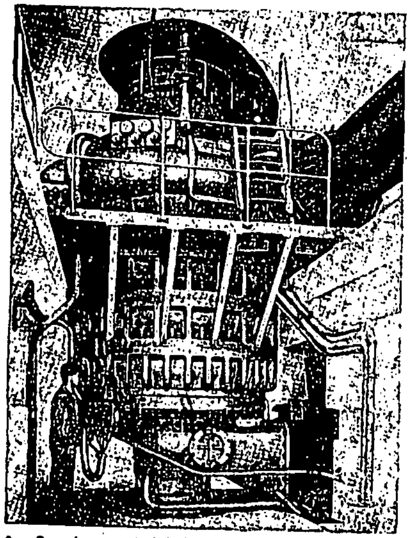
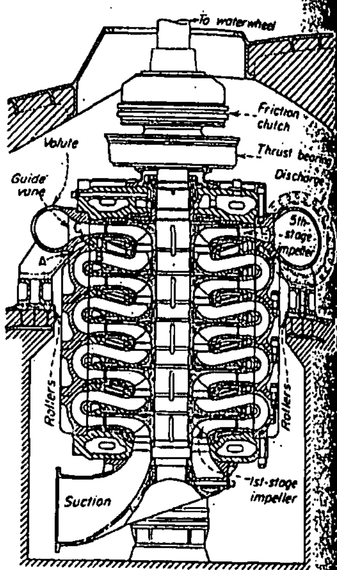
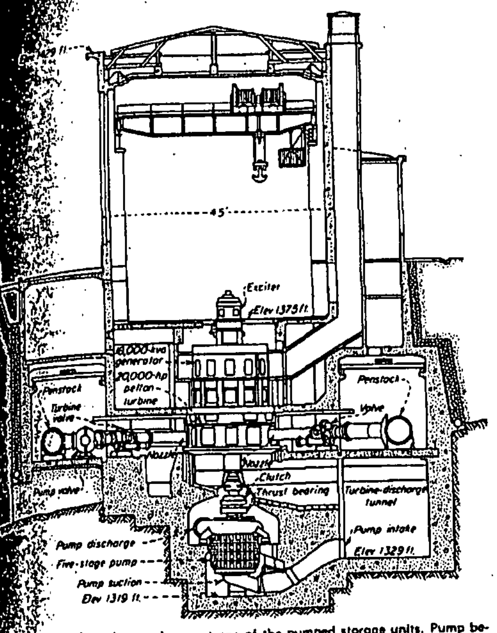


1 One of two vertical-shaft 5-stage pumps, rated 35,525 to 38,165 gpm at 1611- to 1561-ft head, needs 21,450 hp



2 Cross section through one of the 5-stage pumps shows circumferentially-split casing and volute on the last stage



3 Cross section through powerhouse at one of the pumped storage units. Pump below the turbine can be moved out into the assembly space between the two units

Pumped Storage Capacity Improves Big Power System's Operation

Two pumps rated 35,000 gpm against 1611-ft head, installed as part of 120,000-hp high-head hydro plant, economically provide a wide range of power-system operating flexibility

► HYDROELECTRIC PROJECTS that have water-storage reservoirs offer several advantages when operated in parallel with other types of plants on large power systems. Pumping can often supply increased water storage economically when it is needed. A number of conditions, or combinations of them, may justify using off-peak or dump power to pump water into storage for daily or seasonal power generation. In Europe, the Etzel power development represents one of these projects using high heads and a combination of natural runoff and pumped storage for large power output.

Etzel power project, in central Switzerland, near Altendorf, uses the difference in elevation between Lake of Zurich and artificial Lake Sihl, on a river of the same name. Lake Sihl, formed by three dams, has storage capacity of 3.4-billion cu ft (78,000 acre-ft). A tunnel nearly two miles long, designed for 1130 cfs maximum flow, runs through a mountain from Lake Sihl to a surge tank and valve chamber above Lake of Zurich.

Two penstocks extend down to the powerhouse near the lake into which a discharge tunnel empties, Fig. 4 and 5. This 1400-ft discharge is a tunnel 15 ft high by 16.5 ft wide for 1220 ft. Then it widens to 30 ft in an open channel. When the storage reservoir is filled to maximum elevation of 2929 ft, total head to Lake of Zurich is 1586 ft with the lake at mean elevation 1343 ft.

Power Units. Six vertical-shaft 2-nozzle Pelton waterwheels are installed with a nozzle on opposite sides of each wheel. On the operating floor inside the powerhouse along its side walls runs one of the two penstocks, to which a nozzle from each waterwheel connects, Fig. 3. These wheels are each rated 18,000 to 22,000 hp under an effective head between 1381 and 1568 ft. This gives the present plant a capacity of 120,000 hp which will be increased to 160,000 hp when two more units are installed.

Three of the wheels connect to 18,000-kva single-phase 10-kv 16 2/3-cycle generators, which supply power to the Swiss Federal Railways. The other three wheels connect to 3-phase generators of the same capacity and voltage, but designed for 50 cycles. These three units supply power to Nordostschweizerische Kraftwerke A.G.

Pumping Units. When the power project was designed in 1932-33, provisions were made for two 38,000-gpm pumps. But the Swiss Federal Railways and the power company were not sure the extra power that would be made available by the pumps could be used. So they were not installed, but space was provided for them below two turbines. These pumps were not ordered until 1945 when a severe power shortage justified their installation.

One pump connects to the turbine of a single-phase generator and one to that of a 3-phase machine, on either side of the powerhouse transverse center line. They had to be selected not to exceed the power capacity of the generators installed when operated as motors, and were ordered for 38,165 gpm each at 1561-ft head and 500 rpm.

Fig. 2 shows a cross section through one of the two pumps. Their designers had to face the problem that the pumps' foundations had been built ten years earlier for 4-stage pumps. Design improvements and the need for highest efficiency favored 5-stage pumps. To install them in the space available required connecting the pumps to the waterwheels by specially designed friction-clutch couplings.

As the project worked out, Sulzer Brothers built the pumps including their shafts and Escher Wyss supplied the clutches for connecting the pumps to the waterwheels, the step bearings, the spherical seating valves and connecting piping.

Outside diameter of the 5-stage pumps is smaller than that of the 4-stage, and required minor changes in the foundations. For easy assembly and dismantling, the pumps are permanently mounted on rollers, so they can be pushed in or pulled out from under their power units onto the pump-room floor between the two machines, Fig. 4. The powerhouse crane can then handle their parts without any difficulty.

Few pumps of this size have been built for heads over 1600 ft. For this reason construction of their volutes and head covers required new designs for which previous experience was not available. The pumps are a diffuser type, have circumferential split casings with the last stage discharging into a volute.

Volutes, made without external ribs to insure sound castings, are welded to the fourth-stage section of the diffuser casing to avoid concentration of material and stresses. These joints are made with a double circumferential weld, at *A* and *B*, Fig. 2. After making the welds the space between them at *C* was used to hydraulic-pressure test the joints.

Thrust Bearings, Couplings. Because of design, total axial thrust and weight of the rotor, about 100 tons, had to be taken on a thrust bearing. This bearing is supported on the cover plate of the volute. Each pump could have been connected to its turbine by any one of several methods, but to meet space restrictions and have the coupling as simple as possible a specially designed friction clutch was selected.

Installed in each pump's discharge pipe is a hydraulically operated spherical service and a manually operated isolating valve. The service valve closes automatically when pump speed drops to 300 rpm or when there is a serious pressure drop in discharge connection.

Power for Pumping. Surplus power in the system may not be enough for one pump motor, 20,500 hp. Any one of several methods might have been used to control the output, but it was decided to operate the pumps at full capacity when in service. Any deficiency in electric power for a pump generator-motor is supplied by operating its turbine. For example, if only 15,000 hp of surplus power is available for one pump, the remaining 5500 hp is supplied by using part of the pump's discharge to drive its turbine.

In this way the pump is operated at full capacity, but the pump discharges only part of its rated capacity to the reservoir, as if it were throttled. This system of regulating the pump's load has been satisfactory at an efficiency as high as would be obtained by throttling or by using wicket gates.

When power fails, stopping a large pump is a complex problem that requires careful study. Account must be taken of pump speed changes and pressure changes in the piping system. Unless controlled, speed drops quickly, pump's direction of rotation reverses within a few seconds, and the impeller running as a turbine reaches runaway speed of 1.25 times normal.

Reverse operation had to be avoided,

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