Lessons Learned

The Flexible Powerhouse

A horizontal axis, axial flow Kaplan turbine with a draft tube bent into an elongated "S" is often the preferred type of unit for prospective hydro plant sites with available head of between 8 and 25 meters. Such was the case at one particular development, where two units had been aligned and were ready for commissioning.

During start up, the first unit only ran for a few hours before it had to be stopped because the runner blades were coming in contact with the throat ring. The second unit was stopped after about five hours of operation when the oil head bushing seized.

What had gone wrong?

Horizontal axis "S" units are built with a combined guide and thrust bearing — to take the axial thrust from the runner — in a small bulb at the upstream end of the unit. This bulb is joined, by means of stay vanes, to a conical steel inlet section. This section is embedded in the concrete forming the upstream wall of the powerhouse.

At this particular development, the powerhouse was rectangular in shape, similar to that of a shoe box, with the upstream wall of the powerhouse also serving as the downstream wall of the intake. The two horizontal units had direct-coupled generators with a shaft over 16 meters long, from upstream guide/thrust bearing to downstream generator bearing. Powerhouse concrete volume had been kept to a minimum by using a short intake — horizontal distance between trashrack and powerhouse wall was less than 11 meters. Intake height, from turbine floor to headwater, was just over 21 meters.

Both turbine units had been aligned when there was no headwater pressure against the intake. The headpond was filled only a few days before commissioning. This fact, coupled with the turbine contractor's suspicion that movement of the upstream guide/thrust bearing had caused the runner blade contact and the oil head bushing seizure, led to the conclusion that the intake had deflected under pressure from the headpond water.

Inspection of the intake showed no cracking, other than the usual hairline cracks associated with concrete shrinkage on cooling. However, measurements taken on the face of the distributor ring flange (which was bolted to the downstream flange of the conical inlet section) prior to watering up the intake showed that both flanges were vertical to within 50 microns. After watering up, both flanges were found to be inclined downstream by about zero degrees, 2 minutes, which indicated that the intake concrete had deflected.

The water-to-wire equipment contractor now had to prove to the owner, beyond a reasonable doubt, that the unit misalignment was not the contractor's fault. The flange measurements taken prior to watering up were suspect, since, in the water-to-wire contract there was no independent verification of any measurements, and the measurements could not be repeated, since it was not possible to empty the headpond.

The contractor hired a consultant who, after some deliberation, reasoned that, if the intake had deflected under water pressure, some change in the deflection should be evident if the load on the intake was varied. To test this theory, pressure on the intake was reduced by opening the draft tube gates to put back pressure on the unit's wicket gates, which were submerged below tailwater by about 2 meters.

Plumb bobs were hung from brackets anchored into the upstream powerhouse wall, just above the level of the top of the distributor ring, one on each side of each unit. At floor level, about 2 meters below the bottom of the distributor flange, the plumb bobs were immersed in oil-filled heavy steel pots. Micrometers with an electrical contact, accurate to within 12 microns, measured the location of the plumb bob wire with respect to steel brackets welded to four points on the pots.

The contractor took measurements (and the owner verified them) with the draft tube gates closed and the units dewatered, and again with the draft tube gates open. For the two plumb bobs suspended between the units, the measurements showed that the central pier between the units moved upstream by about 250 microns on one unit and 400 microns on the other. (The measurements were taken on different days with slightly different tailwater levels, which could account for the differing movements.) This test confirmed the supposition that the intake deflected under water load. Readings taken on several dial gages at other locations also reinforced the conclusion that the intake tilted under water pressure.

The magnitude of the movements was small, but within the expected range owing to the relatively small reduction in load on the intake because of tailwater pressure, compared with the large headwater load. However, the owner was not convinced; hence, another corroborating analysis was required.

The turbine contractor had built and installed more than 20 similar "S" turbines, and the two at this development were the first to experience alignment problems due to movement of concrete. A search through past records turned up two similar-sized two-unit power plants. The dimensions of the central pier between these units was then compared with the pier at this development.

Because the ability of the pier to resist deflection under load was of prime importance, the consultant developed an equation to express the relative deflection of the central pier, assuming it was a simple vertical cantilever. For the two power plants with no concrete deflection problems, the value of the relative deflection was well below 1,000 units, whereas for this development, it was over 10,000. The flexibility of the upstream concrete wall at this development was *more than ten times* that of the other two plants.

This structural analysis confirmed the physical evidence that the upstream wall of the powerhouse was too flexible. However, an analysis of the concrete stresses in the wall found these to be all within acceptable code limits.

The units were realigned with the upstream wall in the loaded and deflected position, and commissioned with no difficulty.

Lessons learned: The powerhouse concrete structure was designed by civil engineers to recognized standards, but was too flexible to accommodate the more rigid requirements of mechanical equipment. Structural engineers design to stress limits, whereas mechanical engineers design to deflection limits, which result in much lower stress levels — hence the problem encountered at this development.

Turbine-generator manufacturers should specify the allowable deflection or movement permissible in equipment foundations (most likely to be none). Also, power plant designers should be aware that the upstream wall of the powerhouse in horizontal axis "S" units, which contains the turbine thrust/guide bearing, must be sufficiently rigid to resist deflection under water and machine loads.

— By James. L. Gordon, B.Sc., Hydropower Consultant.