

ABSTRACT

Recent advancements in technology, design and manufacture of equipment for small power generating sets have facilitated harnessing the resources of small hydro potential in India. Large number of firms are now manufacturing standard turbo-generating units to suit different head, discharge and other parameter requirements. It has now become possible to have units utilising heads as low as about 2m. Bulb turbines have been developed exclusively for low head power generation. Nowadays the turbines are made as horizontal shaft machines to improve their performance. Generators are coupled in the same turbine shaft and are housed inside the water tight bulb casing. The water flows all around the unit and these types of generating units are normally utilized for exploring heads upto 25m. Conventional vertical shaft Kaplan turbines are used for heads more than 25m upto 50m. Bulb turbines are much better than the conventional Kaplan turbines for low head applications in-terms of hydraulic performance due to better layout of flow passages.

Cavitation in water systems is due to the formation of cavitation bubbles, which results from local pressure falling below the vapour pressure of the flowing water. Cavitation occurs in areas of accelerated flow such as the gap between turbine blade tips and the turbine housing or on the suction side of runner blades. Cavitation can also occur in the gap between the blade roots and hub and in the hub vortex behind the turbine runner. In hydraulic machines, efficiency is reduced considerably due to cavitation and this alters the flow pattern. Loss of energy is caused due to vibration and noise. Pitting of the surface causes loss of material. In hydraulic turbines, the power output is reduced due to cavitation, since the force exerted by water on the turbine blades decreases.

This research study has been carried out in small hydro power plants with eight number of bulb turbines installed in a run-of-river scheme in Tamil Nadu, South India. Experiments have been conducted on all the eight machines at the respective power houses and the results on cavitation pressure, vibration, noise and air injection tests are discussed with the relevant theory.

Compressed air admitted into the discharge ring of bulb turbine, when vibration generated at certain operating conditions, has reduced it by 50%. The stress due to cavitation pressure on the discharge ring is found to be the main cause for its deformation. The noise level during air injection test has been appreciably reduced and smooth running of the machine is noticed.

In bulb turbines, the water flow velocity is much higher at the runner vane outlet, which causes the pressure of flowing water to drop below its vapour pressure. Simulation studies have been carried out using CFD software to study the pressure variation inside the discharge ring of a bulb turbine for different guide and runner vane angles and stability of stay column structures. Simulation results are compared with the experimental data and found to be in good agreement.

There are several sources of vibrations in a hydroelectric power station, which cause problems in every plant design. The generator and turbine shaft supporting the stay column of a bulb turbine, is the route to propagate the vibrations to the concrete structure. Vibrations induced in a machine foundation often have caused poor performance of machine bearings which wear asymmetrically, or cause premature fatigue of machine parts. Vibrations have influenced rapid enlargement of cracks, which might have been initially caused by other factors such as stresses imposed by differential settlements of the foundations. A dynamic analysis of the foundations subjected to vibratory forces has also been carried out.

The main shaft of the turbine is positioned horizontally in a bulb turbine unit. The turbine runner with the runner vanes is assembled at one end of the shaft, and the generator rotor with poles is assembled at the other end. The turbine runner is dynamically balanced at the supplier's machine shop, whereas the rotor and pole assembly is done at the powerhouse site without any static balance. An abnormal vibration with heavy noise is observed during starting and shutting down of the machine chosen for this study.

Also, vibrations occurred in the main shaft and in the water filled casing of the turbines (discharge ring). The dynamic behavior of these vibration

induced in turbines, include both transient and steady state vibrations caused by rapid guide vane/runner vane operations and back water thrust due to deep setting of the machine and unbalanced masses. These vibrations are transmitted to the supporting structure and foundations of the machines. Dynamic amplitudes and velocity of vibration have been measured in this study in various directions. This analysis is necessary for the efficient design of the power station structure to eliminate resonance condition and safeguard the machine and its foundation. An analytical study has also been carried out using ANSYS software to study the structural analysis of stay column and foundation. The vibration induced due to the unbalanced rotating masses and by the water flow vortices are added together and a forced vibration with a heavy shock wave is transmitted to the foundation of the generating unit. This caused the entire civil structure of the power station to vibrate in all directions and attain a peak amplitude of vibration at the resonance condition when the natural frequency of the machine and foundation coincides with each other at the excited frequency.

The following experiments are carried out on the bulb turbine chosen for this work.

- Compressed air is injected into the discharge ring of bulb turbine. Vibration and noise levels are measured on turbine guide vane bearing fitted with ODC, machine foundation and on discharge ring in vertical direction during air injection at normal starting, during mechanical spin, at shutdown at different guide vane and runner vane openings.
- Cavitation effects are studied during air injection with respect to noise, vibration and power output. Investigations are made on cavitation pitting at runner vane and guide vane moving areas. Clearance measurements are made on runner vane and guide vane moving places inside the discharge ring and outer distributor cone.
- A study has been carried out on the critical speed and natural frequency of the main shaft of the bulb turbine. Investigations are made on the natural frequency of the main shaft and machine foundation to alter the critical speed.

The above experiments, investigations and measurements have been carried out on eight bulb turbines. The effects of cavitation and vibration on bulb turbines are analysed and the following conclusions are made.

- Air injection at 4 bar in to the cavitation region has reduced vibration by 50 % and noise level by 10 dB in a bulb turbine of 15,600 kW capacity.
- Power generation is improved by 240 kWhr (units) per day at 36% guide vane opening during air injection in these units.
- The vibration analysis made on the main shaft and foundation of the bulb turbine reveal that stiffener modification to the machine structure and the voids filling with concrete in the foundation reduce the vibration peaks at starting and shutting down of the turbine.
- The starting peak vibration is reduced from 65 microns to 23 microns and the vibration during shutting down is reduced from 240 microns to 140 microns, by providing pipe jacks inside the stay column. The vibration duration is also reduced from 10 - 20 seconds to 4 - 5 seconds.
- Correlations parameters established for various combinations of parameters, which influence, vibration, noise, cavitation factor and specific speed.
- Theoretical reasons are established for the occurring of cavitation vibration, noise and pitting of bulb turbine components, which will help the designer to prevent them before the turbine is manufactured.