CHAPTER 12

CONCLUSIONS AND SCOPE FOR FUTURE WORK

12.1 Conclusions

The Experimental, analytical and computer simulation are carried out on the bulb turbine and its foundation have drawn the following conclusions:

Equation are developed to predict the deformation of discharge ring in the bulb turbine at its sides after a specified number of working hours for the new machine (condition 1) and for the reconditioned machine (condition 2). All the correlations give a good relationship on the deformation of the discharge ring. The discharge ring has to be strengthened to withstand the impact of the cavitation force. The inner surface of the discharge ring has to be coated with 18cr 8Ni alloy steel to resist the cavitation pitting. The bulb turbine operation has to be the avoided at low guide vane openings, from 30% to 50% which lowers the Thomas cavitation factor ($\sigma_P$).

Correlations are developed to check the deformation of outer distributor cone the bulb turbine at its sides after a specified number of working hours for the new machine (condition 1) and for the reconditioned machine (condition 2). All the equations give a good relationship on the deformation of the outer distributor cone. The distortion of outer distributor cone assembly is due to cavitation. The normal shut down on machine has to be done only after ensuring the minimum flow in the tailrace channel by giving enough time to disperse the water in the tailrace channel to pass out in the flowing river. The quick shut down of turbine has to be linked with slow closing devices for guide vane assembly to avoid vacuum.

The critical cavitation factor ($\alpha_c$) is expressed in terms of the specific speed ($N_s$) in equations to predict the inception of cavitation and for the formation of the cavitation bubble in bulb turbine. The equation are much useful in finding out the range of operation of the bulb turbine at the design stage itself without going for a model test. The prediction of critical cavitation factor and bubble cavitation factor at different specific speed for the bulb turbines can be
easily predicted by using the curve fitting equation without going for a detailed model study. The model test results and curve fitting equation for bulb turbines are compared in predicting critical cavitation factor $c_c$ and bubble formation factor. The cavitation severity and its location predicted in the model test conducted for the bulb turbine is found different in the prototypes installed at different locations. The severity of the cavitation in the prototypes, have deformed the runner casings in our study. The scale effect in the model study has been proved, and gives a very close approximation on the results.

In this research, it has been confirmed that admission of compressed air to the low-pressure regions inside to discharge ring cushioned the cavity collapses and reduced the destructive effects of cavitation. The introduction of compressed air at the cavitation region is to break the vacuum there, thus raising the pressure and leading to eliminate the cavitation. The air introduced in this manner forms large bubbles, which are compressed down stream in the high-pressure region but are prevented from collapsing by the cushioning effect of the large quantity of air, which could not be observed by the liquid upon compression of the bubble. The compressed air injection in to the runner vane moving area of the bulb turbine reduced the vibration to 50% and the noise level has been reduced by 10 dB at the lower guide vane openings from 30% to 50%.

The simulation analysis using computer software CFX5.5 is very much useful in finding out the zones of low pressure operations in a bulb turbine without actually going for a physical model test. The results obtained in simulation using computer software CFX5.5 are also inline with the analytical results. When the thickness of the discharge ring material is of 40 mm in the runner vane moving area, the stress induced is more and the material strength is inadequate to withstand water hammer pressure. When the discharge ring made of 50 mm, the stress induced is only $204 \times 10^6$ N/m$^2$ which is very much below the yield strength of $211.5 \times 10^6$ N/m$^2$ for SS41 with a maximum factor of safety of 2. The deformation for 50mm thickness is about 2.658mm, which is 0.3 times lesser than the deformation of 40mm. Hence, it is confirmed that the existing thickness for the discharge ring is inadequate with 40mm thickness using SS41 material. Therefore thickness has to be increased at least to 50mm with SS55 material. From the simulation analysis using ANSYS-5.4 package for
the stability of the stay column it is found that entire load of the bulb turbine is taken care of by the top and bottom stay columns and more stress concentration occurs near the concrete foundation at the junction of stay column embedment. It is confirmed by the simulation using ANSYS-5.4 package that the vibration of foundation can be avoided by providing the pipe jacks inside the stay columns as the stress distribution is even, and the deflection of the stay column has reduced. The modification to the stay columns is found to be better than the existing design in terms of deflection and stress values.

The vibration induced during the mechanical spin of the turbine reveals that there is an unbalanced mass in the rotating system. Since the rotor is assembled at the power house site with the core plate stacking and pole assemblies there is an expected unbalanced mass in the generator portion. The unbalanced mass in the generator rotor causes an abnormal vibration when the turbine shaft attains its critical speed at 70 rpm. A resonance condition is created when the natural frequency of concrete structure coincides with the critical frequency of the rotating masses at the existing condition. Therefore a modification in the stiffness of the supporting structure for the bulb turbine is made to avoid the resonance condition in the operating range of the turbine. The analytical equation derived for the both the condition give very close results compared with that obtained by actual measurements. The increasing the stiffness of the machine has shifted the critical speed of the machine to 85 rpm from 70 rpm and the natural frequency of the machine has increased to 22.67Hz from 18.67Hz.

The maximum vibration at 70rpm with above condition is only 140.648μ, which makes a higher difference of 100μ, when compared with the existing condition. The duration of vibration is 2 to 3sec, which is no harm to the machine. As the critical frequency of the machine is increased to 85rpm and that of the foundation had been reduced to 59.5rpm. There is no chance of resonance condition during starting and shutting down of the machine. Hence stiffness modification to the machine and to the foundation is very much advantageous and the operation is safer.
Increasing the mass of the foundation concrete has also shifted the critical speed to 59.5rpm from 70rpm and the natural frequency of the foundation has also decreased to 15.87Hz from 18.67Hz. The foundation for the machine has to be designed using accepted criteria and not by rule of thumb. The necessary design parameters such as soil constants have to be evaluated at which the machine foundation is to be located. The occurrence of resonance and the consequent effect on increase of vibration amplitudes is one of the most common sources of trouble in machine foundation. This is evidently due to faulty design based on improper estimation of design parameters such as stiffness of supporting media and unaccounted forces in the machine. The high ground water table is responsible for excessive propagation of vibration in the run of river power station as the level of water table is always above the base level of the foundation. Suitable structural measure has to be adopted to change the natural frequency of the foundation and to ensure the required margin of safety from the operating frequency of the machine.

M 150 grade concrete is recommended for block foundations for the bulb turbine to have enough strength. Reinforcement should be used on all surfaces, around openings, cavities, etc., which are to be provided in the body of foundation for mechanical requirements. The minimum reinforcement in block foundations is to be 25 kg/m³ of concrete. The natural frequency of the foundation is reduced by the addition of mass concrete to the base area.

12.2 Scope for Future Work

The scope for future work list is below:

- The air injection can be tried inside of the draft tube liner and vibration & noise levels are to be measured during air injection and recorded.
- The air injection into the discharging is tried only at the top half discharging. Now it is recommended to inject the compressed air into the bottom of the discharging.
- Vibration isolations can be tried with neoprene rubber pads between stay column of the bulb turbine and its foundation. Vibration measurements may be done at this condition on turbine and generator bearings.
• Simulation on vibration isolation can be tried with computer software and results may be compared with the experimental data. A suitable equations for the above condition may be derived.

• Openings below the bottom stay column are to be filled with reinforced concrete. The depth and width of structural cracks measurements are to be made at regular intervals to assess the severity of the damage of the powerhouse building.

• New methods can be developed to increase the natural frequency of the turbine away from its "over speed" range with computer simulation.

• New methods can be proposed to decrease the natural frequency of the turbine foundation to avoid resonance condition with computer simulation.

• Sinking of the machine foundation has to be studied in detail and observation has to be made to measure the same by practical methods.

• The alignment and the stability of the stay columns are to be monitored at regular intervals. A correlation may be developed between deformation of discharge ring, outer distributor cone and concrete wall cracks.

• The air gap between stator and rotor in the generator assembly may be linked with the runner vane and guide vane clearances and suitable equations may be derived for the same.