CHAPTER 3
METHODOLOGY

3.1 Overview of the Chapters

This thesis is prepared based on the additional requirements of research on bulb turbine contain twelve chapters.

Chapter 1 gives a brief introduction of hydro power development, bulb turbine and the run of river scheme with specific problems. 2nd Chapter highlights the literature review. 3rd Chapter gives the methodology used in this research. Experiments carried out are covered in Chapter 4. In Chapter 5 an empirical relationship is developed to predict the critical cavitation factors for the turbine and bubble formation for cavitation inception terms of specific speed ($N_s$). The causes and remedy for deformation of discharge ring is discussed in Chapter 6 whereas in Chapter 7 the causes and remedy for the deformation of outer distributor cone assembly is discussed. Air injection test to check the behaviour of cavitation and to control vibration and noise is discussed in Chapter 8. Stress distribution in turbine components using ANSYS – 5.4 package and simulations using CFX – 5.5 package is discussed in Chapter 9. Vibration analysis in Bulb turbine and its foundation is discussed in Chapter 10 & 11 respectively. Conclusions and scope for further work is discussed in Chapter 12.

3.2 Objectives

The frequent observations of noise and vibration due to cavitation force in the bulb turbines have been studied for this work with the following research objectives based on literature survey.

- To find out a correlation between the rate of deformation of discharge ring and the hours of operation of the machine to predict the time of repairing / replacement of discharge ring and the forces caused by cavitation force and water hammer forces.
• To study the cavitation and repairing technique of discharge ring and the material selection for the bulb turbine to withstand the cavitation forces.

• To find out a correlation between the rate of deformation of outer distributor cone and the hours of operation of the machine to predict the time of reconditioning of outer distributor cone.

• To find an equation to predict the critical cavitation factor ($\sigma_c$) by using the specific speed of the turbine ($N_s$).

• To find out an equation to predict the cavitation factor for bubble formation ($\sigma_{c_bubble}$) on the runner blades of the bulb turbine in terms of the specific speed ($N_s$).

• To predict the cavitation effect on the performance of the bulb turbine by using an analytical solution without actually going for a model test.

• To admit compressed air into the discharge ring at different guide vane and runner vane openings and to find out a relationship between vibration, noise level and guide vane openings to predict the safer zone of operation.

• To analyse the structural stability of the stay column using computer simulation to check for further additional stiffness requirements if any.

• To find out the critical speed of the main shaft of the bulb turbine and checking the resonance condition during starting and shutdown of the machine to avoid the particular range of speed in the operation of the machine.

• To analyse the natural frequency of the concrete for the machine foundation and checking the occurrence of any resonance condition during machine start and shutdown condition. To find out the correlation between the vibration and the stiffness condition of the machine and the foundation. To suggest suitable measures for the modification of stiffness for the machine and its foundation to alter the resonance condition and to avoid the peak vibration during starting and shutdown of the machine.
Discharge Ring Assembly Turbine

Copper pipes for Air Injection

Runner Vane

Runner Cone

Runner

Assembly

Guide Vane Bearing

Housing

Outer Distributer Con (ODC) Assembly

Water Flow Direction

Photograph of Discharge Ring Assembly

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3.3 Methodology used in this Research Work

3.3.1 Air Injection

Air injection has been done into the discharge ring and the vibration measurements have been taken. Air injection method has been adopted to check the inception of cavitation phenomenon. The cavitation phenomenon in bulb turbines occurs due to pockets of vacuum created inside the discharge ring due to partial flow of water. Pressure gauges have been fitted on the periphery of the discharge ring to measure the vacuum created at different location of the discharge ring for each and every rotation of the turbine runner. The cavitation occurrence during the low guide vane openings compressed air has been injected on the top of the discharge ring and the vibration and noise levels have been measured. Similarly the vibration of discharge ring in other axis are measured during air injection and compared with the vibration and noise levels measured without air injection.

Curve fitting equations for the air injection have been formulated and these results are compared with the measured values. Similarly the vibration peaks with air injection and without air injection during starting and shutdown periods are measured and required equations are derived.

Air injection method has been adopted to check the cavitation phenomenon and to eliminate the bad effects of cavitation and vibration to the powerhouse building and machine foundation. The stiffness modification methods to machine and to concrete foundations has been adopted to alter the resonant condition at the critical speed of the machine at 70 rpm which is in the operating range of the machine. These two methods have been followed to predict the effect of cavitation and vibration in bulb turbines.

3.3.2 Vibration

Based on the objectives both experimental and analytical methods are used in this study. Experiments are carried out in the bulb turbines of 15,600 kW capacity. The inception of cavitation at the low guide vane opening and zero runner vane opening during the low discharge of water through the bulb turbine has been detected by the measurement of noise and vibration levels on the discharge ring. The vibration displacements, velocities is measured using Mechanylis is instruments and noise level is measured with acoustic meter.
The vibration on the discharge ring in vertical and axial directions is measured and compared with the allowable limits. This method of finding out the inception of cavitation is much easier compared to other methods as this method is a direct way of measuring the amplitude of vibration generated by the pressure waves created by the cavitation phenomenon. Similarly the noise measurements is also a direct indication of acoustic emissions generated by the pressure waves during the collapse of bubbles taking place inside the casing of the runner vane.

Signature analysis of vibration has been done using this vibration instruments to check the vibration amplitudes. Vibration frequencies during cavitation are measured. This method is very much useful in getting the direct reading on the vibration amplitudes and their respective frequencies at different openings of guide vane and runner vanes for a specific rate of discharge through the bulb turbine. The peak values of amplitude of vibration and the respective resonance frequencies during the starting time and shut-down time has been measured and recorded. For the above measurements the vibration instruments magnetic probe is fixed at the turbine guide bearing in the vertical, axial and horizontal directions to measure the vibration amplitudes and the respective critical frequencies during stating and shut down of the bulb turbine. In this method it is very easy to check the amplitude of vibration in all the three axis and can be easily compared for analysis. Similarly the noise level has also to be recorded inside the shaft room of the bulb turbine for starting and shutting down of the machine. Comparison of vibration on the turbine guide bearing to that of the generator bearing cover has been done after taking the vibration readings on the generator bearings (guide bearing + forward thrust bearing + reverse thrust bearing assembly). Similarly the vibration in vertical direction, horizontal direction and axial direction are taken on the top stay column and bottom stay column to analyse the quantum of vibration transmitted by the turbine and generator shaft to their support member such as the stay column assemblies at top and bottom. This method gives an easy way of comparison of transmission of vibration to the supporting members of the turbine guide bearing and generator guide bearings assembly. The vibration transmitted to the concrete foundation for the entire bulb turbine assembly has been measured during starting and shut-down of the machine and compared with that
of machine vibration and a definite correlation between the machine vibration and the concrete foundations has been found out.

The above results have been confirmed by the peak values in the amplitudes of vibration and to resonance frequency at these respective peak values. Similarly the vibration amplitudes and noise levels has been measured during the power generation at 2 MW and 5 MW and so on and are compared. The critical speed of the machine has been found. The resonance condition occurring at each starting and shutdown period when the machine speed crossing the critical speed has been recorded. The peak values of vibration and noise levels has been measured at the critical speed at the time of starting while the speed is increased from 0 rpm to rate speed of the turbine and from 75 rpm to 0 rpm during shutdown. The peak value of vibration and the resonance frequency has been recorded at the critical speed for the existing stability of the machine and foundation. The stiffness condition for the machine supporting structures (top and bottom stay columns) has been analysed and the resonance condition occurring at the critical speed of the machine has been found out.

Governing equations for the vibration phenomenon in all three axis have been derived and the values are to be tabulated. The actual measurements of vibrations taken on the machines have been compared and graphs are to be drawn. All the graphs drawn show the correlation existing between the governing equations and the actual measurements and thus the results are validated. Similarly the stiffness for the foundation has been analysed and a governing equation has been proposed to the foundation vibration at starting and shutdown conditions.

Increasing the base area of the foundation and closing the openings in the foundations have modified the existing stiffness to the machine foundations. Vibrations measurement has been taken on the foundation and compared with modified equation results for the modifications made on the stiffness of the machine foundations. The stiffness modifications to the machine structure and the machine foundations have shifted the critical speed of the machine over and above its rated speed. Hence the resonance conditions have been avoided during starting and shutdown of the machine. Governing equations has been modified for this condition and the analytical results have been compared with the actual test results. The stability of the stay column assembly has been checked with simulation software for the existing stiffness conditions and for the modified condition. The results are compared with the analytical and test
results. The modification to the machine supporting structures are made out at the top stay column and bottom stay. Similarly the voids are filled in the machine foundation and pipe jack supports are arranged to the pathway openings to modify the stiffness in the foundations. Thus a methodology of finding out the peak vibration at the critical speed of the machine and shifting of the resonant condition at the critical speed of the machine has been adopted in this research. Similarly the resonance occurred at the natural frequency of the machine foundation has been measured and the natural frequency for the machine foundation has been modified with the existing stiffness of the foundation concrete.