8.1 Introduction

Air injection test is conducted in bulb turbine as per the experiment setup described in Chapter 4. During the air injection test, the pressure of the compressed air is maintained at 4 bar into the discharge ring. The compressed air is injected through of 4 x 16 mm dia copper pipes. These copper pipes are fitted on the top half of the discharge ring and are placed exactly on the PCD of rotating runner vanes. The vibration on the discharge ring on vertical and axial directions are measured and recorded as given below. The noise level is also recorded during the air injection. The vibration and noise levels are recorded during air injection and without air injection.

It is observed that vibration and noise levels are appreciably reduced during the air injection for guide vane openings from 30% to 50% due to higher areas of low pressure. There is a less reduction of vibration and noise level from 50% to 90% due to the less area of low pressure. The model test result of manufacture says that GVO should be more the 50% for normal operation of the turbine, to avoid cavitation at lower guide vane openings due to decrease in the suction height ($h_s$) of the turbine.
8.2 Air Injection Test and Results

Fig. 8.1 Comparison of vertical vibration of discharge ring

Comparison of vertical vibration of discharge ring during air injection test is shown in Fig. 8.1. A drastic reduction of vibration level for discharges from 40 m$^3$/s to 120 m$^3$/s is noticed during air injection. A noticeable reduction of vibration level in the vertical direction is noticed for the discharge more than 120 m$^3$/s.

Fig. 8.2 Comparison of axial vibration of discharge ring

Comparison of axial vibration of discharge ring during air injection test is shown in Fig. 8.2. A drastic reduction of vibration level for discharges from 40 m$^3$/s to 70 m$^3$/s is noticed during air injection and a noticeable reduction of vibration level in the axial direction is noticed for the discharge more than 70 m$^3$/s.
Comparison of noise level measurements on discharge ring during air injection test is shown in Fig. 8.3. A drastic reduction of noise level for discharges from 40 m$^3$/s to 70 m$^3$/s is observed during air injection and a noticeable reduction of noise level is observed for the discharge more than 70 m$^3$/s.
8.3 Vibration and Noise Level during Air Injection Test

Equation: \( s_2 = -0.0002t_2^2 + 0.1735t_2 + 24.3266 \)

Fig. 8.4 Vertical vibration of discharge ring with air injection

The vibration in the vertical direction obtained by curve fitting equation during air injection is compared with the measured vibration level and is shown in Fig. 8.4. An equation for vibration in the vertical direction has been derived by using Matlab software as \( s_2 = -0.0002t_2^2 + 0.1735t_2 + 24.3266 \), where \( s_2 \) = vibration in vertical direction in micron and \( t_2 \) = discharge of water through turbine. The curve fitting equation gives very close results, which can be used for the prediction of the amplitude of vibration on the discharge ring during air injection.
Equation: \( u_2 = -0.0001v_2^2 + 0.0879v_2 + 56.5398 \)

**Fig. 8.5 Vertical vibration of discharge ring without air injection**

Similarly the vertical vibration amplitudes obtained by solving an equation for without air injection is compared with the measured vibration amplitudes and shown in Fig. 8.5. This equation for vibration in the vertical direction has been derived as \( u_2 = -0.0001v_2^2 + 0.0879v_2 + 56.5398 \), where \( u_2 \) = vibration amplitudes in vertical direction in micron and \( v_2 \) = discharge of water in m\(^3\)/s. As the above equation gives most approximate values the equation can be used for the calculation of the peck amplitudes of vibrations on the discharge ring during the turbine operation without conducting air injection test.
The amplitude of vibration in axial direction obtained by solving an equation during air injection is compared with the measured vibration amplitudes with air injection and is shown in Fig. 8.6. The equation for vibration in the axial direction has been derived as $w_2 = -0.0001x_2^2 + 0.1669x_2 + 35.9155$, where $w_2 =$ vibration in axial direction in micron and $x_2 =$ discharge of water in m$^3$/s. As the above equation gives most approximate values the equation can be used for the calculation of the peck amplitudes of vibrations on the discharge ring during the turbine operation without conducting air injection test.
Equation: \( y_2 = 0.0001z_2^2 + 0.0763z_2 + 53.3238 \)

**Fig. 8.7 Axial displacement of discharge ring without air injection**

Similarly the amplitude of in axial direction vibration obtained by solving an equation for without air injection is compared with the measured vibration amplitudes without air injection and is shown in Fig. 8.7. The curve fitting equation for vibration in the axial direction has been derived as \( y_2 = 0.0001z_2^2 + 0.0763z_2 + 53.3238 \), where \( y_2 \) = vibration in axial direction in micron and \( z_2 \) = discharge of water in m\(^3\)/s. These points show a very close relationship with each other. Hence these equations can be used to calculate the amplitudes of vibration in the axial direction when the machines are running at normal operation without air injection test. Thus the prediction of the vibration amplitudes in the bulb turbine is made easy with this equation.
The noise level variation obtained by solving the curve fitting equation during air injection is compared with the measured noise level with air injection and is shown in Fig. 8.8. The governing equation for the noise level has been derived as \( a_3 = -0.0004b_3 + 0.1346b_3 + 78.6914 \), where \( a_3 \) = noise level in dB and \( b_3 \) = discharge of water in m\(^3\)/s. These points show a very close relationship with each other. Hence these equations can be used to calculate the amplitudes of vibration in the axial direction when the machines are running at normal operation without air injection test. Thus the prediction of the noise level in the bulb turbine is made easy with this equation.
8.4 Results and Discussion

Vibration of 60µ and noise level of 93dB measurements are taken on the top of the discharge ring in the vertical direction at shut down by manual operation. The vibration and noise levels are measured at different mode of operation and it is to be noted that the peak values for vibration and noise level are obtained at the shutdown of the machine generating 2 MW compared with shutdown of the machine generating 5 MW due to sudden and quick closing of runner vane at 2 MW due to increase in water vapour rates. The maximum vibration level measured is 76 microns and noise level measured is 107 dB at shot down with 2MW load.

Vibration and noise level measurements are taken on the turbine guide bearing in horizontal direction. The vibration and noise levels are measured at different mode of operations. It is to be noted that the peak values of vibration.
and noise level are noticed during shutdown at the machine at 2 MW compared with shutdown of the machine at 5 MW. The maximum value of vibration measured is 240 microns and that of noise level measured is 120 dB due to water vapour.

The compressed air at 4.9 bar is admitted to the discharge ring through the four numbers of copper pipes when the machine is running with the following condition.

Guide vane opening 32%
Runner vane opening 1.0%
Head on the machine 7.20m
Discharge in the machine 40 m$^3$/sec
Speed of the machine 75 rpm

A 50% reduction in vibration has been achieved and a reduction of 10 dB is achieved in noise level with air injection and this is a quite appreciable result for smooth and efficient performance of the turbine. Then the test is continued with 36% guide vane openings and the results are given below.

Guide vane opening 36%
Runner vane opening 2%
Head on the machine 7.20m
Discharge in the machine 50 m$^3$/sec
Speed of the machine 75 rpm

Vibration and noise levels are measured and recorded.

The above test results show that the 46% reduction in vibration has been achieved and a reduction of 8 dB in noise level with air injection and this is a good and appreciable result for a machine to get a smooth and efficient performance. Then the test is continued with other guide vane openings. All the test readings show that the vibration and noise levels are reduced very much and smooth running of the turbine is established. Hence it's confirmed that air injection is very much essential in a bulb turbine to reduce vibration and noise level in discharge ring and in guide bearing. The compressed air pressure is varied from 4.9 to 3.2 bar to avoid cavitation inception inside the discharge ring.
8.5 Conclusions

Leading edge cavitation on the runner and at the discharge ring has been experienced in this study. Air injection is tested successfully to minimize cavitation erosion and is found to be very effective in minimizing cavitation erosion in bulb turbine. A 10 dB noise reduction and 50% vibration suppression have been recorded during this air injection experiments.

The cavitation noise has profoundly influenced by the following factors (i) number and size distribution of cavity bubble (ii) cavity generation rate and (iii) impact force on the solid boundary are also confirmed.

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 introducing of compressed air at the cavitation regions 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 curve fitting equations can be used to predict the vibration and noise levels in the bulb turbines without actually going for an air injection experiment, which will be a very useful tool for the designer of the bulb turbines.