ON SITE PRESSURE PULSE MEASUREMENT OF HYDRAULIC MACHINES

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ABSTRACT

Pressure pulsations can not be avoided in hydraulic turbines pressure pulsation but it will affect performance and life. The intensity and amplitude of pressure pulsation depends on the flow pattern, flow rate, pipe diameter, operating head and load fluctuations on the machine. The intensity of pulsation also depends on the location of measurement also. The intensity of pulsation was recorded for various loading condition. Pressure pulsation studies were conducted at different locations of the country for different types of machines as Francies turbines at Sampalpur (MP), Kaplan turbines at Ajonsol (UP), Francies turbine at Tehri (Uttaranjal) etc . Pulsation measurements were done at different locations of a hydraulic system like penstock, spiral casing and draft tube areas as per the IEC 60994. During the measurement static pressure and turbine loads are noted down. Dynamic Pressure waves were recorded with high natural frequency pressure sensors. The recorded signals were analyzed using FFT analysers to segregate the frequency spectrum and correlate to the turbine speed and other related parameters. The instruments used in this test for qualitative analysis of pressure pulsation include a dynamic pressure transducer, Charge amplifier, and analyzer. The samples were recorded at a sampling rate of 1, 50,000 samples per second for different loading condition from minimum to rated. Unsteady vortex flow, Improper closing and opening of turbine and gate valves, air entrainment in the sealing and Inlet guide vane angles are found as the reasons for pressure pulsation during the operations. This is very useful technique to monitor the heath of the hydraulic machines during the operation.

Key Words: Pressure pulsation, Hydraulic turbines, cavitation, aeration, sealing, health monitoring

1. INTRODUCTION

Hydraulic machines

Hydraulic Turbines transfer the energy from a flowing fluid to a rotating shaft. Based on the flow path of the water inside the machine Hydraulic Turbines can be categorized is Axial Flow, Radial Flow, and Mixed Flow machines. One more classification based on the pressure change it can be classified as Impulse Turbine, Reaction Turbine**.** Francis and Kaplan Turbines fall in the category of Reaction Turbines.

The Francis turbine is a type of water turbine that is an inward flow reaction turbine that combines radial and axial flow concepts. It is the most common water turbine in use today and operates in a head range of ten meters to several hundred meters for electrical power production. The Kaplan turbine is a propeller-type water turbine which has adjustable blades. Its invention allowed efficient power production in low-head applications. It is widely used throughout the world in high-flow, low-head power production. The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy.

Aeration, Cavitations & Pressure pulsation

Aeration occurs when excessive vacuum is created between the machine and the reservoir. Aeration may also occur when components have been worn or damaged and can no longer contain normal system vacuum. Under these conditions, outside air is pulled in and mixes with the water. This creates froth on the pressure side of the turbine that lessens system efficiency and creates excessive noise as the air bubbles whistle past components in the system. Aeration often occurs simultaneously with cavitation.

Cavitation may appear to be a major problem in hydraulic power machines. Cavitation affects hydraulic power machines and components in various ways. For example efficiency of a system is reduced due to cavitation and vibrations as well as noise level of a system is increased.

Even low-pressure, Kaplan turbines can cause cavitation. In the case of hydraulic machines, it's extremely important that the proper intake or suction is installed, and the clamps are tight enough to prevent any leakage. Air is being drawn into the system through a leak, while cavitation is caused by a collapsing water vapor. Aeration can occur either before or after cavitation begins. Aeration is less likely to cause damage, but it's a good indicator of a service problem.

Aeration-cavitation occurs when the local pressure in the water flow falls below the saturation point. This causes dissolved air to come out of solution in the form of air bubbles. Detection of cavitation can be done directly only by verifying the existence of cavities. Direct detection is possible by observing visually the population of developed cavities in flow passages. However, hydraulic power machines encompass usually complicated constructions and cavitation can occur in various locations where the access for visualisation instruments is limited. Due to restrictions of direct detection of cavities, various indirect methods can be used. In these indirect methods the measurements are typically targeted to the shock waves generated by cavity implosions.

When detecting cavitation indirectly, the question is typically about measuring the shock waves induced by cavity implosions. Cavity inception is at first seen in very high frequencies, and therefore very fast transducers are needed. Shock waves can be recorded in the cavitating fluid with high-speed pressure transducers. The propagation of shock waves continues from fluid to the surrounding component body and measurement of the acceleration of the component surface reveals the presence of cavitation.

Cavitation produces broadband high-frequent noise. Noise is emitted when the cavities collapse violently and high pressure peaks are generated. Incipient cavitation may not be audible to human ear but developed cavitation can be identified from distinct sizzling or crackling noise. Using microphones and sound level meters, also incipient cavitation can be recorded. Cavitation is most likely to occur near the fast moving blades of the turbines and in the exit region of the turbines. Cavitation can occur near the fast moving blades of the turbine where local dynamic head increases due to action of blades which causes static pressure to fall. Cavitation also occurs at the exit of the turbine as the liquid has lost major part of its pressure heads and any increase in dynamic head will lead to fall in static pressure causing Cavitation.

Pressure pulses are fluctuation in the basic pressure being developed by hydraulic machinery due to varying reasons. The pressure fluctuations are symptoms of malfunctioning of the turbine. These pulsations can sometimes be very severe and cause damage to the piping systems. In a hydro turbine a pressure pulse is developed as each rotating blade passes the water to the discharge section at maximum to minimum energy level. This can also be due to gas present, cavitation present etc. Pressure pulsation is oscillatory variation of the pressure of the liquid referred to its mean value during a time interval. Periodic pulsation is a quantity whose values recur at equal intervals of the independent variable (time). Frequency is the reciprocal of period. Amplitude is the maximum value of a sinusoidal quantity. Peak to peak value of an oscillating quantity is the algebraic difference between the extreme values of the quantity. In the case of sinusoidal quantity the peak to peak value is twice the amplitude.

2. METHOD FOR MEASUREMENT OF PRESSURE PULSATION

Pressure pulsation will normally be measured in significant locations of the hydraulic system such as at the high pressure side of the machine (if necessary in the penstock), in the draft tube, in the wet surface of the head cover.

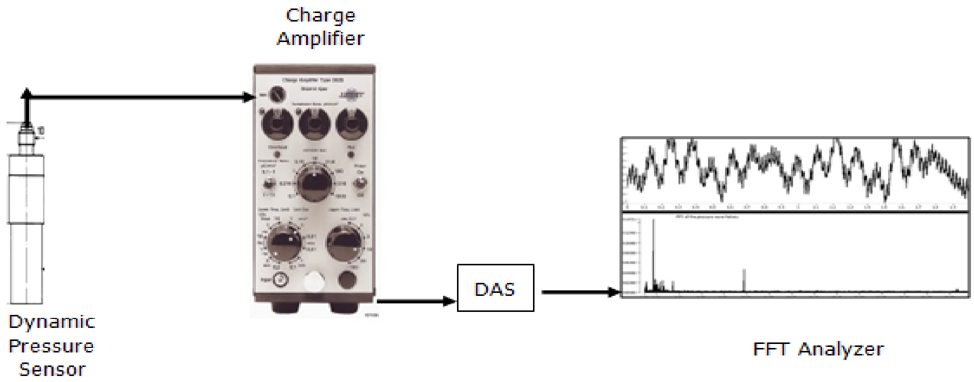

Fig.1 Schematic of the Experimental Setup for pressure pulse measurement

Pressure pulsations have two important characteristics, frequency and amplitude. The instruments used in this test for qualitative analysis of pressure pulsation are a dynamic pressure transducer, Charge amplifier, Data acquisition systems (DAS), FFT analyzer and a static pressure transducer. Figure1 above shows the schematic of test set up employed for measuring dynamic pressure wave history.

Dynamic pressure transducer is a device to convert the pressure pulse in to a charge, which in turn is converted to voltage, and it is a vibration compensated device. DAS is a device to capture the voltage fluctuations and it will store in a PC. FFT analyzer is used to convert the pressure wave history to frequency domain so that it can be correlated to turbine speed and causes of fluctuation can be identified. Measurement setup and locations are shown in plate A.

The transducers should possibly be fixed flush with wet wall; otherwise special care shall be taken to eliminate the risk of resonance and damping effects in the connecting pipe(Refer Figure 2). The above fixing should also minimize the sensitivity to mechanical shocks and avoid secondary oscillations in the connecting pipe.

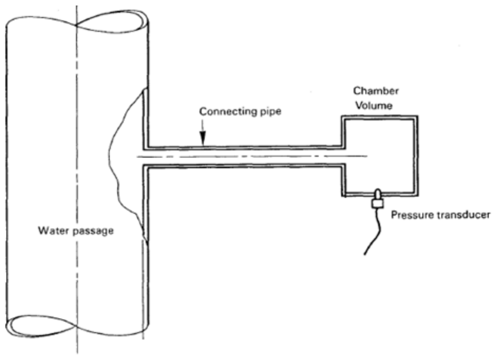

Fig.2 Schematic arrangements of pressure transducer mounted with connecting pipe

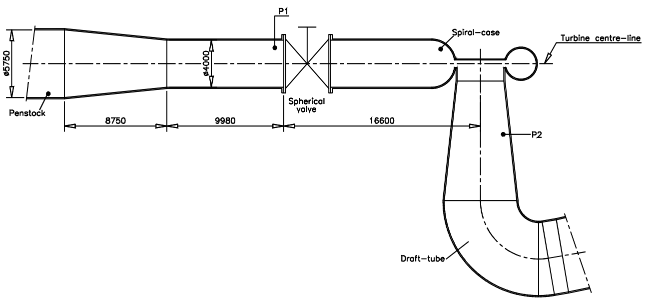

Fig.3 Schematic of the Vertical Francis Turbine at the site

Peak to peak values of pulsation are investigated to provide an indication of the level of pulsation at given measuring point. These types of analysis are very regularly made of pulsation test. In this kind of analysis only amplitude values are considered while frequencies ate disregarded. In cases where repetitive sharp peak (“ spikes”) are characteristic of the oscillatory process the average value of the peal to peak values should be calculated to serve as measure of the general level of pulsation.

3. TESTING AT SITE

The hydraulic machine at site is a Vertical Francis turbine.
The specifications of the turbine are given below:
Turbine Make/Type : Power Machines/Vertical Francis
Rated capacity of the Unit : 255 MW (100%)
Rated Discharge at Rated head : 145.1 m^3/sec

Rated Speed : 214.24 RPM
Diameter of Penstock : 5750 mm
Diameter of Runner : 4100 mm
Diameter of Spiral casing : 5600 mm
Rated net head : 200 m
No of turbine blade : 18

Pressure Pulse testing of Hydro power station has been done in three locations of Penstock, Spiral casing, and Draft tube area for various loading conditions. Vibration compensated dynamic pressure sensor has been used to measure the pressure pulsation of the machine. The recorded sample values were analyzed by FFT Signal processing. Operating condition of pulsation tests performed. Machine at no load and speed increasing step by step to specified speed.

Fig.4 Photograph of the Instruments arrangement at the site

Fig. 5 Dynamic pressure sensors and Static Pressure sensors arrangements

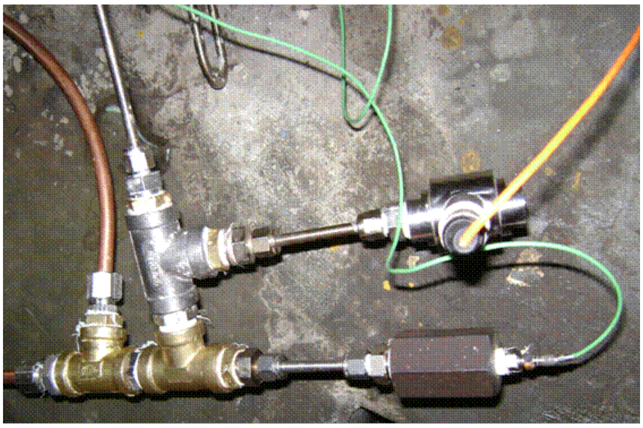

Fig.5 Photograph of the Hydraulic machine at the site

The pressure pulsation had been recorded in the power stations at penstock, spiral casing and draft tube area. Dynamic pressure sensor and static pressure sensors are mounted in the particular place and connected to DAS though a charge amplifier. The samples were recorded at a sampling rate of 1,50,000 samples per second for different loading condition from minimum to rated. During each loading condition, static pressures are also noted down. Recorded values are analyzed by FFT analyzer. Time and Frequency domain graphs are plotted. Measured dynamic pressure values are qualitative measurements, and it should not be comparable to any other results.

4. RESULTS

The samples were recorded at a sampling rate of 1,50,000 samples per second. Duration of each sample is 1 second. The recorded samples are analyzed using FFT analyzer and the first two peak values and its frequency and amplitude has been noted. Figures 6-9 show the plot of the pressure fluctuation recorded by the transducer and the corresponding FFT spectrum at the penstock spiral-casing junction at different loading locations in the system. The results of the rms value of pressure fluctuations and the frequency corresponding to maximum amplitudes at three locations at various loading conditions are listed in Table 1-4. Figure 10-13 shows the maximum amplitude obtained from frequency spectrum analysis. This gives two predominant frequencies observed in the FFT plot. Pressure pulsation was measured penstock, spiral casing and Draft tube locations.

Test results

Table 1 Pressure pulsation test Results - Unit-1

% of load	Location	RMS	Peak	No of peaks
75	P	5.39	7k,52k,58k	3
85	P	2.04	7k,52k	2
60	P	3.62	7k,52k,60k	3
100	S	5.19	7k,52k,60k	3
85	S	2.57	7k,15k	2
75	S	4.39	7k,18k	2
60	S	9.72	7k,52k,60k	3
100	D	0.646	7k,18k	2
85	D	0.610	10k,20k,30	2
60	D	2.29	7k,12k,22k	2

Table 2 Pressure pulsation test Results- Unit -4

%of load	Location	RMS	Peak	No of peaks
100	P	1.54	7k,15k,25k,35k	4
70	P	2.76	7k,10k,15k,30k,35k	4
60	P	1.44	7k,15k,1ok,32k,35k	5
75	P	1.64	7k,10k,15k,20k,25k,30k	6
100	S	1.94	7k,15k,10k,20k,25k	6
75	S	3.17	7k,10k,20k,30k,35k,40k	6
70	S	2.33	7k,10k,15k,20k,30k	5
60	S	3.27	7k,10k,15k,20k,30k,35k	6
100	D	0.615	7k,10k,15k,20k	4
75	D	1.45	7k,10k,15k,25k,30k,35k	6
70	D	1.65	7k,10k,15k,20k,25k,30k	6
60	D	2.26	7k,10k,15k,20k,22k	6

Table 3 Pressure pulsation test Results-Unit -2

% of load	Location	RMS	Peak frequency	No of Peaks
60	D	0.683	60k	3
75	D	0.554	55k,60k,30k	3
85	D	0.387	30k,50k,60k	3
100	D	0.168	30k,52k	3
100	S	0.168	30k,52k	3
85	S	1,63	7k,60k,2k	4
75	S	0.693	7k,20k,60k	4
60	S	0.885	7k,15k	3
100	P	0.333	7k,15k,40k	3
85	P	0.515	7k,15k,35k	3
75	P	0.319	7k,15k,25k	3
60	P	0.821	7k,15k,20k	3

Table 4 Pressure pulsation test Results – Unit-3

% of load	Location	RMS	Peak frequency	No of Peaks
60	P	88.9	7k,42k	2
75	P	164.64	7k,42k,45k	3
85	P	252.83	7k,42k,57k	3
100	S	536.86	7k,42k	2
100	S	245.24	7k,42k,52k	2
85	S	143.64	7k,42k	2
75	S	122.67	7k,42k	2
60	D	46.74	7k,42k	2
100	D	71.66	7k,42k	2
85	D	368.17	7k,42k	3
75	D	123.85	7k,30k,42k	3

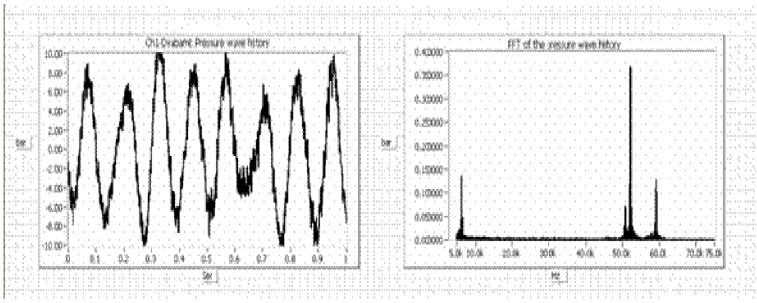

Fig.6 Unit 3 Penstock location @ 75% loading condition

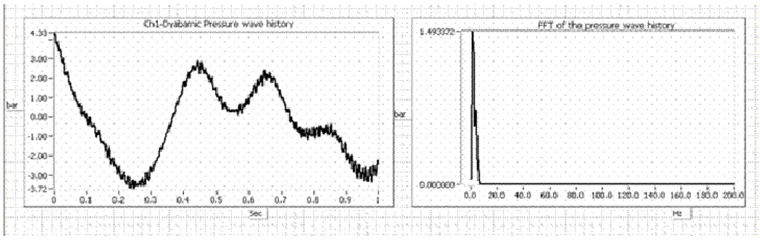

Fig.7 Unit 3 Draft tube location @ 75% loading condition

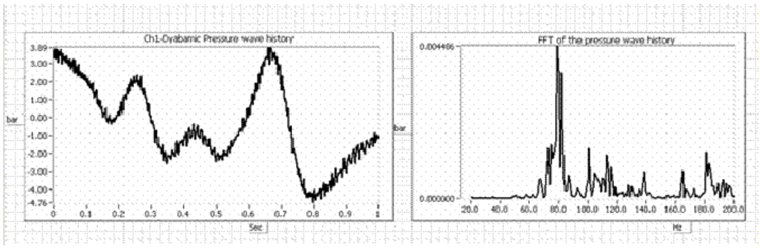

Fig.8 Unit 3 Draft Tube location @ 60% loading condition

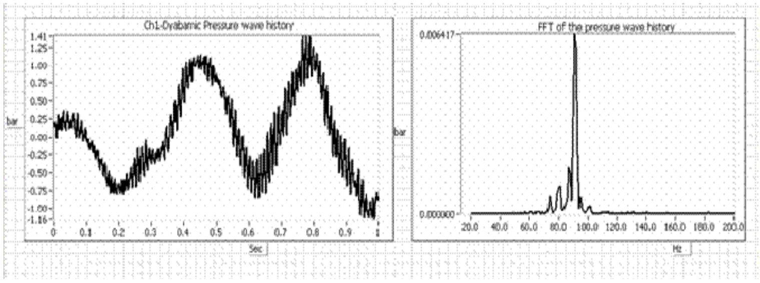

Fig.9 Unit 3 Draft Tube location @ 85% loading condition

Sample Pressure wave and FFT of the Pressure waves

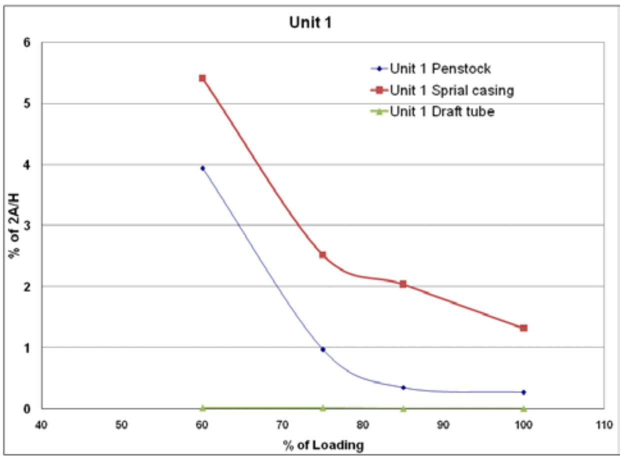

Fig.10 Unit 1 Peak to Peak Vs % loading condition

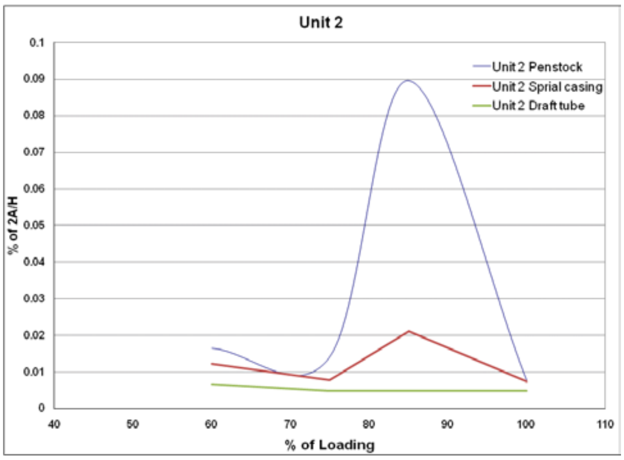

Fig.11 Unit 2 Peak to Peak Vs % loading condition

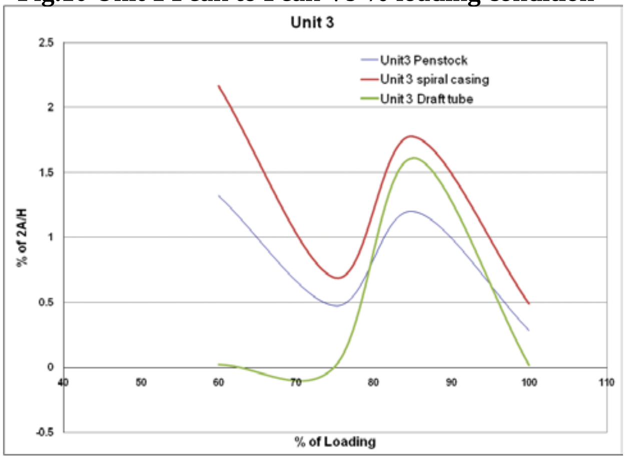

Fig.12 Unit 3 Peak to Peak Vs % loading condition

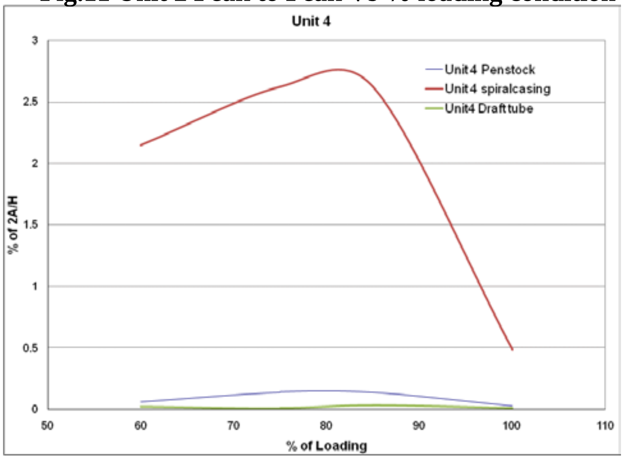

Fig.13 Unit 4 Peak to Peak Vs % loading condition

5. CONCLUSION

a. Compare to other units, unit no 3 is having higher amplitude of pressure fluctuations. It shows that some disturbance is present in the flow passage area. It is suggested to check the Blade angle and erosion which will cause vortex rope in the turbine. Unsteady vortex flow in the penstock will produce the pressure pulsations.

b. Unit 3 the pressure fluctuation is more and it is ±10 bar (amplitude). For other turbines, fluctuation was within ±3 bar. This increase may be due to cavitation or aeration of the turbine no 3. Improper closing and opening turbine and gate which will cause air leakage and air entrainment. Air bubbles will cause pulsation flow in the turbine. Further study needed for cavitation presence.

c. From the above results (table 4), the pressure pulsation were more in the intermediate loading condition and Full load condition for the Spiral casing and full load and near full load condition for the penstock. This may be due to bend

d. It can also be seen that the frequency of fluctuation is more in the second maximum amplitude. The pulsation amplitude is more in the penstock compared to the draft tube area. It can also be seen that, the frequency of maximum amplitude is location specific. FFT results also indicate the possibility of cavitation present in the machine -3.

e. At No load and near full load operations, pressure pulse frequency is between 1-1.9 kHz. This may be due to flow disturbance and can be attributed to flow noise present due to high velocity.

f. Other machines the amplitude values are less and there is no significant values of pressure variation so that machine no 1,2,4 are working quite.

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