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Vibration Monitoring System for Optimum Operation of Hydraulic Turbine at Nam Ngum1 Hydro Power Plant

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ABSTRACT

The hydraulic turbine of Nam Ngum1 hydro power plant in Lao PDR has been operated for more than 20 years. From the inspection, the damage from cavitation has been found on the turbine casing and runner blades. Therefore, in this work, the vibration monitoring system is applied for measuring cavitation because of the increasing vibration with the cavitation level. In this work, the 40MW hydraulic turbine unit#5 of Nam Ngum1 HPP is selected, as research specimen. This turbine is a vertical shaft Francis turbine. The vibration transducers are mounted at turbine bearing, turbine casing and draft tube. In this experiment, the turbine load is varied between 15-45 MW, while the water level is between 32-45 m from tailrace level.

The results from experiment show that the vibration level is directly proportional to the water level. Moreover, it is found that when turbine load lower than 20 MW, the vibration increases with the reduction of turbine load. However, when the turbine load is higher than 20 MW, the vibration is directly proportional to turbine load. From the vibration result, the proper operation of turbine at various water levels has been considered for reducing the cavitation of turbine.

Keywords: Vibration monitoring system, Hydraulic turbine, Optimum operation

1. INTRODUCTION

At present, the hydro power plant plays an important role on the social-economic development and the increasing standard of living in Laos PDR. The hydro power plant has been developed significantly at an accelerated rate [1]. Laos has the development strategy to increases the installation capacity of hydro power plant for meeting the domestic demand and increase the export electricity. Actually, Laos has substantial hydropower resources approximately 18,000 MW [1]. There are many rivers throughout the country. Moreover, Laos locates in a monsoon zone and receives heavy rainfall over 3,000 mm annually. These conditions provide a lot of water for producing electricity.

Electricite Du Laos (EDL) is a state owner utility and responsible for power generation, transmission and distribution in Laos PDR. At present, EDL has total installation capacity of 306.5 MW (EDL, 2005) [17]. Nam Ngum1 Hydropower plant is the largest power station which belongs to EDL. It is supply the electric energy to Central-I Area of Laos PDR and Thailand. At present, Nam Ngum1 has 5 units of hydro-generator and detail of each unit is shown in Table 1.

Table 1 the installation capacity of hydro-generator of Nam Ngum1.

Unit	Capacity (MW)	Installation Year
1	17	1968-1971
2	17	1968-1971
3	40	1976-1978
4	40	1976-1978
5	40	1983-1984

Most of hydroelectric power plants which belong to EDL have never been studied for major damage. In case of Nam Ngum1 hydro power plant, the hydraulic turbine has more than 30 years and 24,000 hours operation. From the previous literature the hydraulic turbine must be inspected in case of the running time more than 24,000 hrs. [2]. Cavitation can appear in hydraulic turbine under different form depending on the hydraulic design and the operating conditions. In Francis turbine the main types are leading edge cavitation, traveling bubble cavitation, von karman vortex cavitation and draft tube swirl. Leading edge or inlet cavitation is usually a very aggressive type of cavitation that is likely to deeply erode the blades. Traveling bubble cavitation is noisy type of cavitation that can reduce significantly the machine efficiency and provoke blades erosion. Periodic shedding of von karman vortex cavitation at the trailing edge of blades can provoke their cracking due to vibration under lock-in conditions. And finally, draft tube swirl generates low frequency pressure pulsation that in case of hydraulic resonance can cause strong vibrations on the turbine [3].

The problems such as vibration abnormal noise in turbines, cavitation erosion and other troubles of Num Ngum1 hydroelectric power plant have been found. To prevent serious damage, this research will be analyzed the particular damage on hydraulic turbines of Num Ngum1 hydroelectric power plant. In this work, the hydraulic turbine unit 5 of Num Ngum1 is selected as a case study.

From the inspection, the damage from cavitation is found on the turbine casing and runner blades. This result comes from lack of cavitation monitoring system. Therefore, sometime, the turbine is operated in unsuitable condition. To overcome this problem, the vibration monitoring system is applied for measuring cavitation because of the increasing vibration with the cavitation level.

2. RESEARCH METODOLOGY

In this work, the hydraulic turbine unit#5 of Nam Ngum1 HPP is selected as research specimen and Table 2 shows the detail of this turbine. The vibration of the turbine is measured by mounting the vibration transducers at each turbine point which is as follows:

PC1Vibration measuring point at housing bearing at axial x

PC2 Vibration measuring point at housing bearing at axial Y

PC3 Vibration measuring points at head cover

PD1Vibration measuring point at draft tube

The vibration of the turbine is measured by mounting the vibration transducer at each turbine guide bearing (PC1, PC2), head cover (PC3) and draft tube (PD1). These measuring point are show in the figure 1. The vibration data is collected by using vibration analyzer Type CSI model 2120 and accelerometer model 726 SN2979 having frequency response between 2.0-10,000 Hz.

Table 2 Characteristics of tested turbine. (NG1HPP)

No.	Power plant	Nam Ngum1 HPP Unit#5
1	Type of turbine	Francis Vertical
2	Out put	40 MW
3	Over speed	310 rpm
4	Rotation speed	136.4 rpm
5	Full water level	El 212 m
6	Minimum operate	El 196 m
7	Maximum head	45.5 m
8	Runner dia metter	4,230 mm
9	specific speed	230

Turbine unit 5

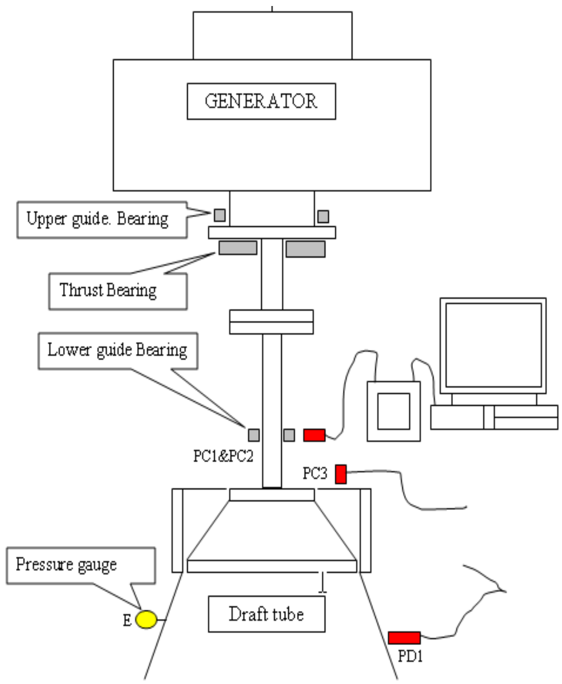

Figure 1 the positions of vibration measuring point of turbine unit#5.

3. RESULTS AND DISCUSSION

The vibrations of turbine at various measuring points are shown in figures 2-6. In all cases, the water level and turbine load are between approximately 32-45 m from the tailrace and 15-45 MW respectively. Notice that the maximum load of this turbine is 40 MW. This mean, the turbine runs overload in some conditions. In case of figure 2, the result shows the relation of turbine load and vibration in term of the vibration amplitude (RMS velocity; mm/s). In this case, the water level is 32.38 m and turbine load is 15-29 MW. It is found that most of the vibration is lower than 2 mm/s except the vibration of draft tube at load of 15 MW, the vibration is around 2.5 mm/s. Moreover, it is found that the vibration of draft tube is the highest while the rests are nearly the same (around 0.2-0.5 mm/s). At 20 MW load, the result shows the lowest vibration of all measuring point.

When the water level is increased, it is found that the vibrations of all measuring points are increased too. These results are shown in figures 3-6 which the water levels are equal to 35 m, 40.3 m, 42.75 m and 44.29 m respectively. In each case of water level, the results are also shown the highest vibration at draft tube and the rest measuring points have nearly the same vibration level. Moreover, it is found that the lowest vibration point is shifted from 20 MW (case of water level = 32.38 m), 25 MW (case of water level = 35 m), 35 MW (case of water level = 40.3 m) and 40 MW (cases of water level = 42.75 m and 44.29 m). The vibration of turbine normally comes from cavitation.

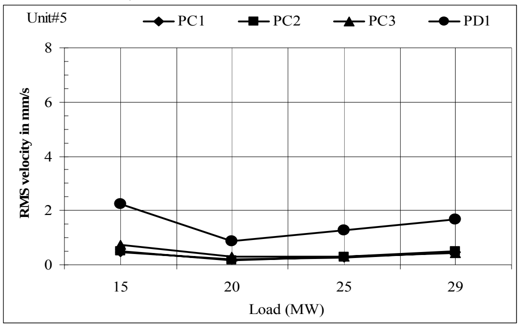

Figure 2 Vibration amplitude at various loads; Water level = 32.38m

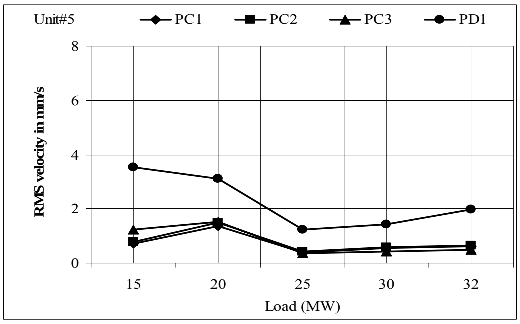

Figure 3 Vibration amplitude at various loads; Water level = 35m

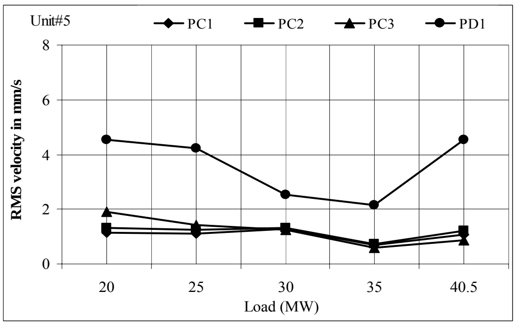

Figure 4 Vibration amplitude at various loads; Water level = 40.30 m

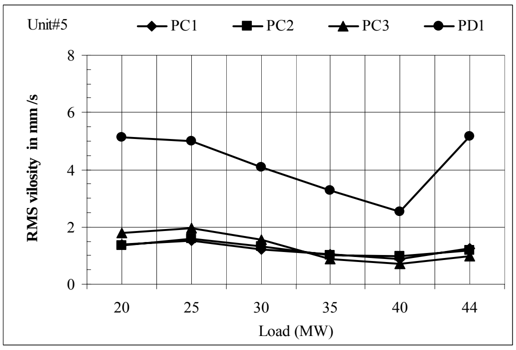

Figure 5 Vibration amplitude at various loads; Water level = 42.75 m

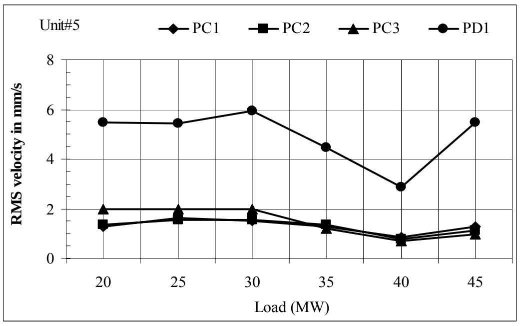

Figure 6 Vibration amplitude at various loads; Water level 44.29 m

Actually, the cavitation of hydraulic turbine brings to get the severe damage of material facing. Figure 7 shows the damage of turbine runner blades for Nam ngum1 hydro power plant.

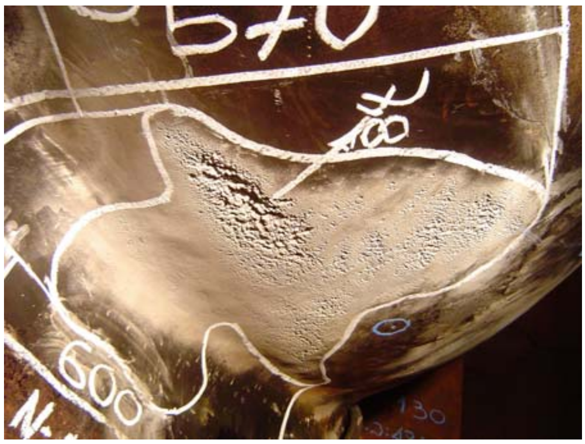

Figure 7 the cavitation damaged of turbine runner blade.

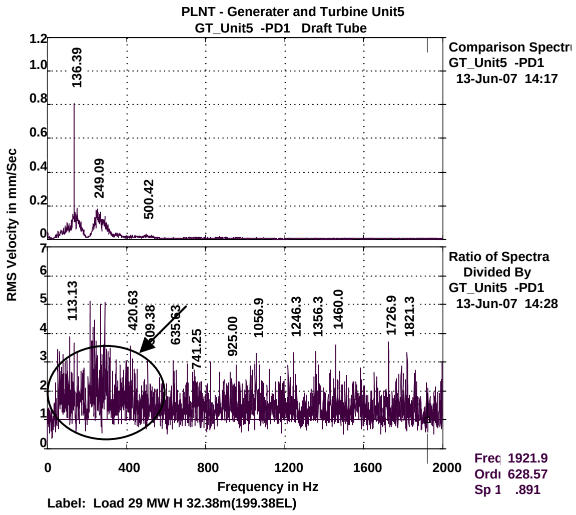

Figure 8 Comparison spectrum load 29 MW divided by load 20 MW at PD1, the water level 32.38 m

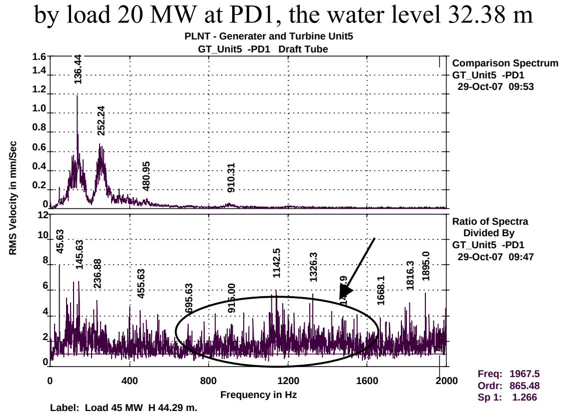

Figure 9 Amplitude ratio of unit #5 at PD1 load 45 MW divided by load 40 MW, the water level 44.29 m

From the vibration spectrum analysis, it is found that the cavitation of hydraulic turbine is enormously occurred at low water head and high water head. In case of low water head (32.38 m), the cavitation occurs at load 29 MW. On the other hand, in case of high water head (42.75 m), the cavitation occurs at 44 MW (overload). When the cavitation occurs, the shape of vibration spectrum looks like a group forest which shown in figures 8-9

To avoid of cavitation, the operator should be run turbine Load at 20 MW if the water level 32, 38 m, turbine Load at 25 MW if the water level 35 m, turbine Load at 35 MW if the water level 40.30 m, turbine Load at 40 MW if the water level 42.75 m and turbine Load at 40 MW if the water level 44.29 m.

From above results, the cavitation of turbine always occurs when the turbine load is higher than normal load of each water level, especially, at low water level-maximum load and high water level-over load cases. These phenomena could be explained by using the principal of fluid mechanics [4] as follow:

In comparing the cavitation characteristics of turbines it is convenient to define a cavitation parameter (σ) as

$$\sigma = \frac{P_{atm}/\gamma - P_v/\gamma - Z_B}{h}. \qquad (1)$$

Where, σ Cavitation parameter
P_{atm} Atmospheric Pressure (Pa)
P_v Vapor Pressure (Pa)
h Net head (m)
γ the specific weight, 9.81 kN/m^3
Z_B Elevation (m)

Where Z_B and h are as defined in figure 10. The minimum values of σ At which cavitation occurs is σ_c Its value can be determined experimentally for a given turbine by noting the operating conditions under which cavitation first occurs as evidenced by the presence of noise, vibration, or loss of efficiency. Typical values of σ_c are shown in table3

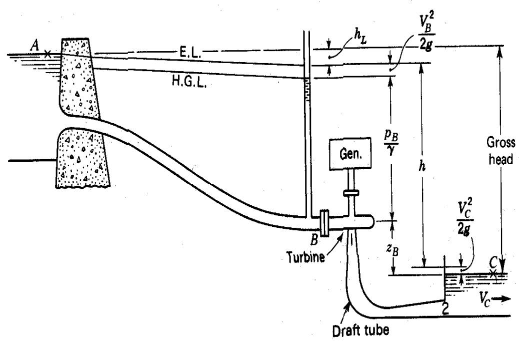

Figure 10 Net head on reaction turbine [4].

Table 3 the minimum value of cavitation parameter at various specific speeds [4].

	Francis turbines				Propeller turbines		
n_s	160	240	320	400	400	600	800
σ_c	0.10	0.23	0.40	0.64	0.43	0.73	0.5

It should be noticed that the specific speed of turbine is defined as

$$n_s = \frac{n_e\sqrt{bp}}{h^{5/4}}. \qquad (2)$$

Where, n_e is turbine speed in rpm and bp is net power of turbine.

In case of the turbine is operated more than the designed load at various water level which shown in figure 10 (for example, at water level = 45 m the designed load = 40 MW). The specific speed of turbine is increased and this condition brings to get higher minimum value of cavitation parameter. However, in this case, the cavitation parameter calculated from equation (1) is nearly constant. Consequently, the probability of $\sigma < \sigma_c$ is increased and the cavitation of turbine is obtained. This explanation agrees well with high and low water levels.

4. Conclusion

From this experiment, it can be concluded that, vibration of turbine depend on the load of turbine. When load of turbine increase, vibration trend to get higher too. From the research, so to avoid of cavitation, the operator should be run turbine load at 20 MW if the water level 32.38 m, turbine load at 25 MW it the water level 35 m, turbine load 35 MW if the water level 40.30m, turbine load 40 MW if the water level 42.75m and turbine load 40 MW if the water level 44.29m

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