

Small Hydro Power System: Measurement of Turgo Turbine Vibration Level Using VIBSCANNER Analyzer

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Abstract

Cavitations are among the most frequent severe damage that occurs on the mechanical part of hydro turbine, especially to its runner blades. This phenomenon is unpredictable, will affect efficiency, increase of noise level and vibrations. Typical approach of cavitation detection is based on feeling of vibration pulsations on the surface of the guide vane stem. This cavitation effect can also be seen happened to the Turgo turbine operated at the Sg Perting Small Hydro Power System. In this research work, vibration signal (in terms of velocity) is recorded using VIBSCANNER analyzer periodically in one hour interval for a few hours running. The data is then analyzed using OMNITREND PC Software. On top of that, the signals can be displayed in the form of frequency spectrum, generated via Fast Fourier Transform (FFT) computation. By referring to ISO Standard 18316, types of failures can be identified and this will prevent catastrophic machine failures occur in future.

Keywords: Cavitation, Turgo Turbine, vibration, VIBSCANNER Analyzer, Fast Fourier Transform, frequency spectrum.

INTRODUCTION

Turbine is the main component in hydropower technology that transformed hydro potential into mechanical energy. This converted energy will be further used to drive generator for the purpose of electricity generation. There are two types of turbines that widely used in hydropower industry; either impulse or reaction type. Whichever types that were used, the cavitation problem on the turbine is unavoidable. Cavitation is developed due to formation of voids or bubbles contributed by the rapid changes of liquid ^[1]. When the changes in liquid pressure occurred, the voids will be burst and causing a strong shockwave. The reaction type of turbine, such as Francis and Kaplan is more likely to experience this cavitation phenomenon as compared to impulse type. Amongst the factor to which the cavitation will influence the hydro turbines including ^[2]:

- Machine setting level
- Operating condition at various load

- The runner design
- Off-design operational condition

Technically, there are numbers of engineering methods were implemented to detect cavitation. There are method of measuring the change of efficiency, visualisation of flow by an electronic capacitive charged device (CCD), measuring of sound pressure and measuring of vibration structure by locating appropriate transducer adjacent to the runner blade or draft tube ^[3]. In this research works, measurement is carried out by using built-in transducer available in this analyser.

The time-domain representation gives the amplitudes of the signal at the instants of time during which it was sampled. However, in many cases you need to know the frequency content of a signal rather than the amplitudes of the individual samples. Fourier's theorem states that any waveform in the time domain can be represented by the weighted sum of sines and cosines. The same waveform then can be represented in the frequency domain as a pair of amplitude and phase values at each component frequency. In the frequency domain, you can separate conceptually the sine waves that add to form the complex time-domain signal. The previous figure shows single frequency components, which spread out in the time domain, as distinct impulses in the frequency domain. The amplitude of each frequency line is the amplitude of the time waveform for that frequency component. The representation of a signal in terms of its individual frequency components is the frequency-domain representation of the signal. The frequency-domain representation might provide more insight about the signal and the system from which it was generated. Time domain signal can be converted to Frequency domain signal with the use of Discrete Fourier Transform or Fast Fourier Transform (FFT).

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The fast Fourier transform (FFT) provides a method for examining a relationship in terms of the frequency domain. Fourier's theorem states that any waveform in the time domain can be represented by the weighted sum of sines and

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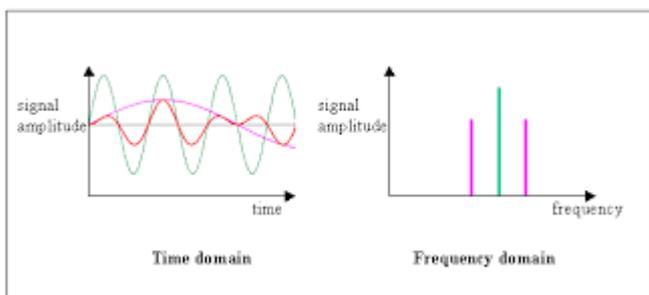


Figure 1: Conversion from time domain to frequency domain [13]

There are several ISO requirements need to be complied with when performing condition monitoring, particularly related to vibration analysis. These include ISO 10816 Vibration Severity Standards and ISO 18436-2:2003 which specifies the general requirements for vibration analysis personnel who perform machinery condition monitoring and diagnostics of machines.

MEASUREMENT SYSTEM SPECIFICATIONS

A. Turbine specifications

A Turgo turbine, as in Fig 2.0 is a type of turbine, developed in the 1920s, that is a variant of the Pelton turbine. The main difference between a Pelton turbine and a Turgo turbine is that Turgo turbines use single cups instead of double cups on the wheel, and these cups are more shallow.[14]

The Turgo turbine is an impulse turbine, and can handle flow rates that are higher than those a Pelton turbine can handle. This ability to deal better with large volumes of water gives the Turgo turbine an advantage when used in hydroelectric plants that have medium hydraulic heads.[14] Although they are better able to deal with high flow rates, Turgo turbines are slightly less efficient. [15]

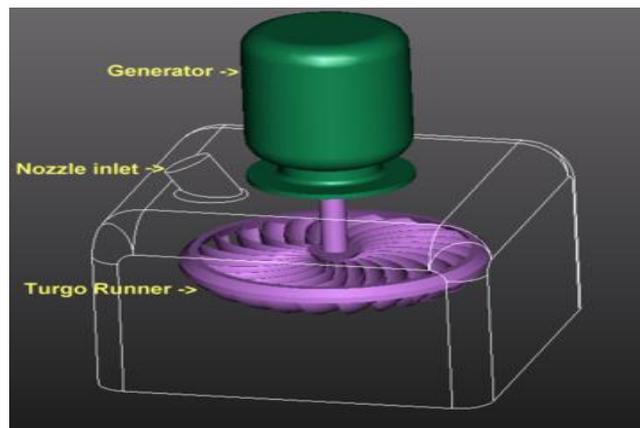


Figure 2: Turgo Turbine [16]

Since the runners on these turbines are smaller and faster spinning, some Turgo turbines can be connected directly to a generator instead of having to use a speed-increasing transmission. This direct attachment is shown in Fig 2.0.

The technical specifications of Sg Perting Hydropower generating unit are as the following:

- i. Voltage : 690V
- ii. Frequency : 50 Hz
- iii. Current : 2092.0 A
- iv. Output : 2500 KVA
- v. Speed : 750 l/min

The specifications of Turgo turbine as below:

- i. Head (H): 159.60 m
- ii. Flow rate (Q): 1620 l/sec
- iii. Power (P): 2181 kW
- iv. Speed (n): 750 rpm

HYDROLOGY	
Hydrological Region	Perting River, Bentong, Pahang
Water Resources	1200 – 1600 mm/year
Physiographic	Hilly and mountain complexes
INTAKE STRUCTURE	
Intake Span	19m across river
Settling Basin	The 19m intake has a settling basin designed to allow sufficient time for 0.5mm size particles to settle
Overflow Weir	2.5m height, constructed across the river to divert water into the settling basin
Water Head	159.6 m (net)
Flow	3.2 cu-m/sec
PENSTOCK	
Length	3800 m
Diameter	1400 mm
Material	Steel pipe coated with epoxy

Figure 3: (a) Sg Perting Hydro Plant Specifications

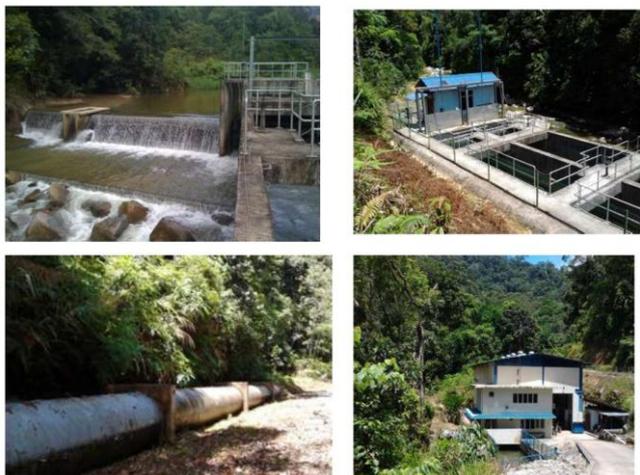


Figure 2: (b) Hydro Plant Structure

B. Vibration Analyzer

It comes with modular structure, all-rounder handheld and can be navigated via one-hand joystick. The instrument can withstand harsh environment due to its waterproof and dustproof enclosure and design.

The main features of this analyser including:

- ✓ 3 built-in sensors: VIBSCANNER measures the most important machine parameters on rotating equipment such as vibration, cavitation, bearing condition (shock pulse), temperature and RPM.
- ✓ Modular design: VIBSCANNER can be upgraded to a vibration analyser by simply adding the “signal analysis” firmware module that allows you to perform orbit & phase analysis, time waveform analysis and long-term time waveform recording.
- ✓ Versatile vibration analysis tools: VIBSCANNER can detect machine problems such as unbalance or misalignment and can perform the necessary corrective actions with the optionally available firmware modules for field balancing and laser shaft alignment.

With OMNITREND, the universal Condition Monitoring software platform, measurements can be stored and analysed. Diagnosis reports can be generated; measurement tasks can be pre-configured and uploaded to the device for route-based data collection.

As with all our data collectors and vibration analysers, you will benefit from free software and firmware updates, and low ownership cost.



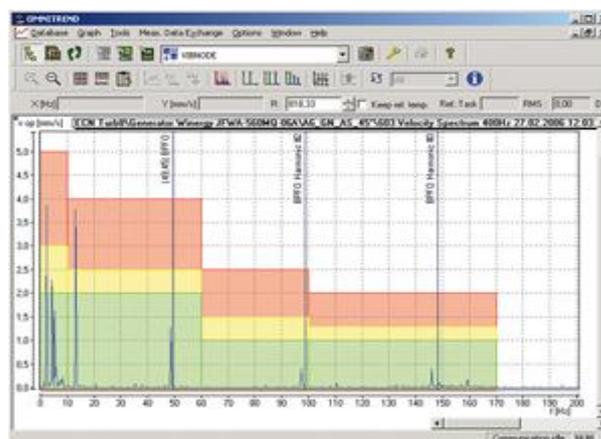
Figure 3 (a): VIBSCANNER vibration analyser [21]



Figure 3 (b): Measurement using VIBSCANNER [21]

C. Analysis software tool

OMNITREND is the universal and powerful software platform for Condition Monitoring systems (handheld and online systems). OMNITREND manages your periodic measurements and provides you with efficient and powerful analysis tools: Overall vibration trends, shock pulse readings, FFT spectra, envelope filtering and many more modern measurement functions help you diagnose machine problems efficiently. Dynamic narrow frequency band alarms detect machine failures like unbalance, misalignment, bearing failures, resonance, looseness or gear problems. Overall alarms can be set individually, or the predefined ISO alarms as per DIN ISO 10816 can be easily added to keep track of your asset’s condition. There is comprehensive bearing fault frequency database included in OMNITREND that will be a benefit for identifying specific failures and their root cause.



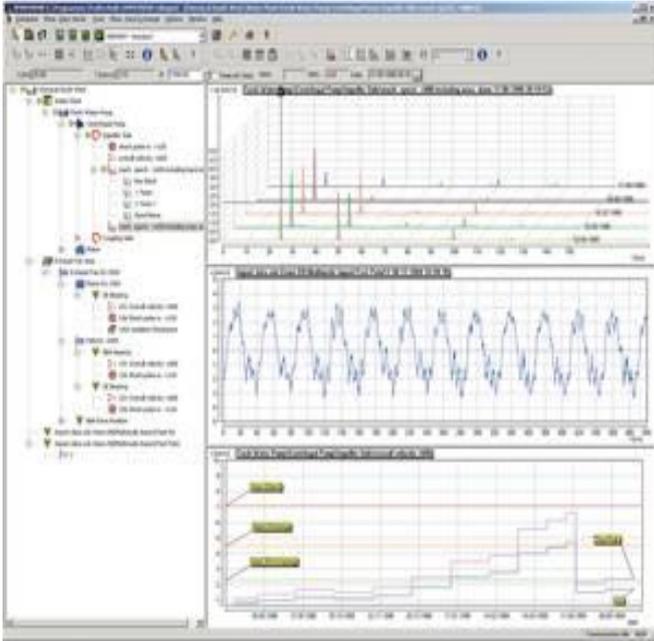


Figure 4: Examples of analysis under OMNITREND [22]

D. Applied mathematical equation

A fast Fourier transform (FFT) algorithm computes the discrete Fourier transform (DFT) of a sequence, or its inverse. Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa. An FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors.[17] As a result, it manages to reduce the complexity of computing the DFT from $O(n^2)$ which arises if one simply applies the definition of DFT, to $O(n \log n)$, where n is the data size.

Fast Fourier transforms are widely used for many applications in engineering, science, and mathematics. The basic ideas were popularized in 1965, but some algorithms had been derived as early as 1805.[18] In 1994, Gilbert Strang described the FFT as "the most important numerical algorithm of our lifetime"[19] and it was included in Top 10 Algorithms of 20th Century by the IEEE journal Computing in Science & Engineering.[20]

The fast Fourier transform (FFT) is a discrete Fourier transform algorithm which reduces the number of computations needed for N points from $2N^2$ to $2N \lg N$, where \lg is the base-2 logarithm.

Fast Fourier transform algorithms generally fall into two classes: decimation in time, and decimation in frequency. The Cooley-Tukey FFT algorithm first rearranges the input elements in bit-reversed order, then builds the output transform (decimation in time). The basic idea is to break up a transform of length N into two transforms of length $N/2$ using the identity

$$\sum_{n=0}^{N-1} a_n e^{-2\pi i n k/N} = \sum_{n=0}^{N/2-1} a_{2n} e^{-2\pi i (2n) k/N} + \sum_{n=0}^{N/2-1} a_{2n+1} e^{-2\pi i (2n+1) k/N}$$

$$= \sum_{n=0}^{N/2-1} a_n^{\text{even}} e^{-2\pi i n k/(N/2)} + e^{-2\pi i k/N} \sum_{n=0}^{N/2-1} a_n^{\text{odd}} e^{-2\pi i n k/(N/2)},$$

Figure 5: FFT Identity of Danielson Lanczos Lemma

sometimes called the **Danielson-Lanczos lemma** as indicated in Fig 5.0. The easiest way to visualize this procedure is perhaps via the Fourier matrix.

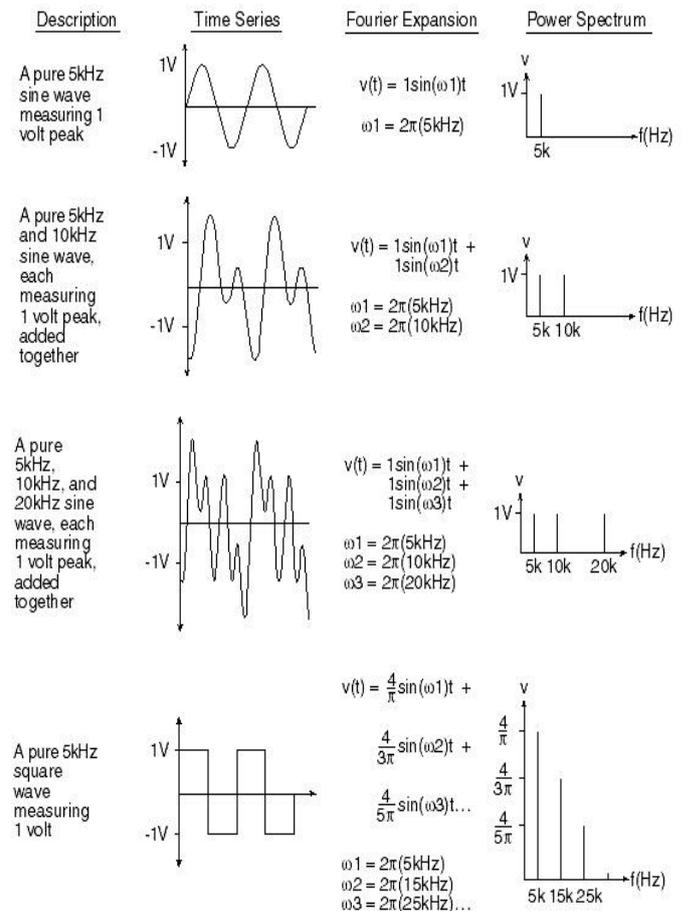


Figure 7: The Fourier Transform illustrated

MEASUREMENT SYSTEM SET-UP

a. System set-up

Figure 7 show the system set-up that comprises of two major components of hydropower system; Turgo Turbine and asynchronous AC motor



Figure 7: Turbine and Generator Unit 2

Multi-point measurement is performed at the DE (driving end) located at the rear end of turbine and front of the generator unit and also at the NDE (Non-driving end), located at the end of generating unit. Measurements are done horizontally, vertically and axially.

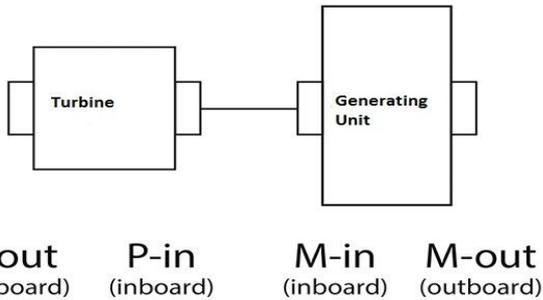
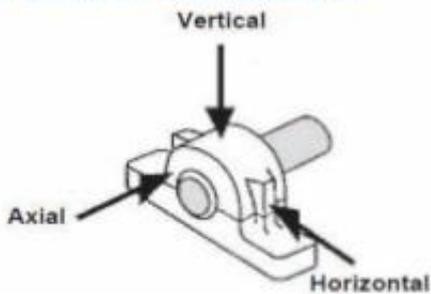


Figure 8: (a) Measurement lay-out

Measuring Techniques



Measuring at bearing points in three directions:
 Horizontal
 Vertical
 Axial

Figure 8 (b): Measurement axes

b. Analyser setting parameter

Measurement parameters are the details that will specify how a measurement is to be carried out. By stipulating measurement parameters, data to be collected can be specified and processed before it is accessible to us. The parameters configured for the analyser can be categorized into four classes; namely, parameters that determine:

(a) How data is collected

- 'Trigger type' is the parameter that tells the instrument how to begin measuring
- 'Settling time' is the time required for the accelerometer and instrument to settle before measurements can be taken accurately

(b) How much or how fast data is collected

- The parameters that determine how much or how fast data is collected are the parameters 'Fmax', 'Spectral lines', and 'Overlap percentage'

(c) How data is processed

- The parameters that determine how data is processed are the parameters 'Average type', 'Number of averages', and 'Window type'

(d) How data is displayed

- The parameters that determine how the spectrum is to be displayed are listed under 'Display units'

c. Data Measurement

The amplitude and frequency units to be used in the spectrum need to be specified. The velocity unit and frequency unit usually used are mm/s and Hz respectively



Figure 8(a): Horizontal measurements



Figure 9(a): Vertical measurements



Figure 9(c): Axial measurement

PRELIMINARY RESULT

There are two (2) units of Turgo turbine that had operated at Sg Perting Hydropower. They have running well for several years until one of the turbine had experienced broken blades. Preliminary observation had suggested this might due to cavitation formed at the blades as well as vibration that was developed within the major components of the system (turbine and generator). Fig 11.0 shows the damaged blade of turbine for the generator unit 2.



Figure 10: Damaged Turbine Blades

For the purpose of data capturing, the following parameters have been set-up throughout the whole cycle of measurement process. Fig 12.0 (a) – (c) illustrate the analyzer configuration.

- a) Vibration velocity
 - 10Hz – 1 KHz
- b) Measurement
 - Overall velocity > 120
- c) Transducer Specifications
 - Measurement Type: Acceleration
 - Signal type: Internal Transducer
 - Linear from (Hz): 10
 - Linear to (Hz): 10,000
 - Resonance frequency (Hz): 36,000
- d) Measurement (Overall velocity)
 - Signal type: Sum
 - Measurement type: velocity
 - Frequency from (Hz): 10
 - Frequency to (Hz): 1,000
 - No. of average: 4
 - Average (delays): 1.0
 - Average type: Linear
 - Measurement range: Auto



Figure 11 (a): Configuration of measurement parameter



Figure 11 (b): Configuration of transducer type



Figure 11 (c): Example of measurement data

Measurement data is to be analyzed using OMNITREND Software. In the preliminary stage, measurement points must be configured under Machinery Manager Set-up. This process is to associate with actual measurements performed at machinery sides. Figure 13.0 shows the configuration.

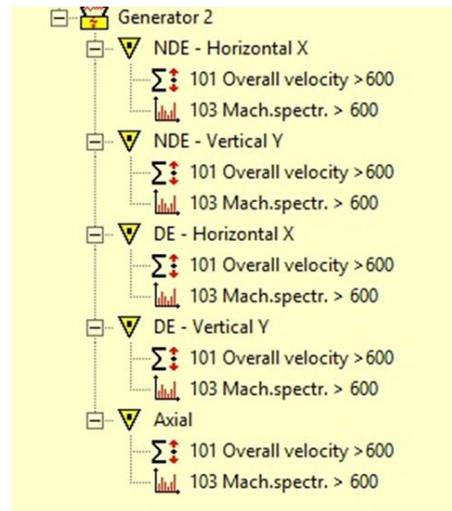
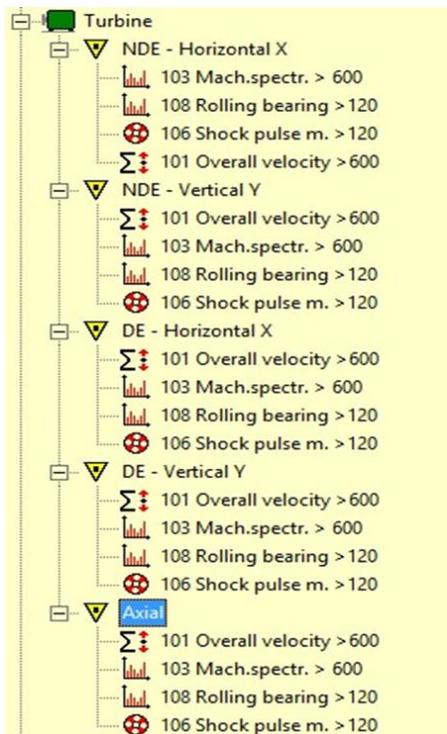
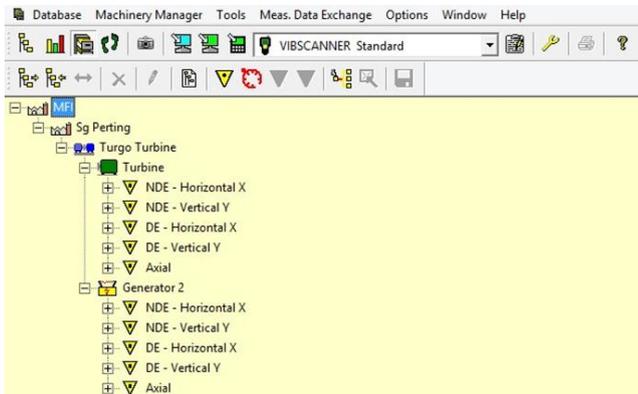


Figure 12: Machinery Manager Set-up within OMNITREND software

Two set of samples data have been recorded until this stage; one is captured in the month of March (dry season) and the other set on month of May (normal season). Table 1.0 and Table 2.0 indicate these set of sampling data respectively

During this measurement, the upper and lower needle valve to control volume of water flowing into runner of turbine is set to 40% open.

Table 1: Vibration level at turbine driving end (DE)

Position	Axis	Hours	Velocity (mm/s) rms
Driving End	Horizontal (X)	12.00	4.19
		13.00	4.9
		14.00	3.69
		15.00	3.98
		16.00	3.77
		17.00	3.87
18.00	3.67		

Position	Axis	Hours	Velocity (mm/s) rms
Driving End	Vertical (y)	12.00	4.15
		13.00	4.17
		14.00	4.83
		15.00	3.93
		16.00	4.73
		17.00	4.91
18.00	4.44		

Position	Axis	Hours	Velocity (mm/s) rms
Driving End	Axial (z)	12.00	3.93
		13.00	4.07
		14.00	3.55
		15.00	4.06
		16.00	3.52
		17.00	3.53
18.00	3.52		

Table 2: Vibration level at generator driving end (DE)

Position	Axis	Hours	Velocity (mm/s) rms	Generated output (Kw)
Driving End	Horizontal (X)	11.00	4.19	945
		12.00	4.9	722
		13.00	3.69	722
		14.00	3.98	852
		15.00	3.77	852
		16.00	2.85	850
		17.00	3.03	980

Position	Axis	Hours	Velocity (mm/s) rms	Generated output (Kw)
Driving End	Vertical (Y)	11.00	4.19	945
		12.00	3.34	722
		13.00	4.48	722
		14.00	3.78	852
		15.00	4.18	852
		16.00	4.13	850
		17.00	4.12	980

Position	Axis	Hours	Velocity (mm/s) rms	Generated output (Kw)
Driving End	Axial (Z)	11.00	1.26	945
		12.00	1.31	722
		13.00	1.39	722
		14.00	1.38	852
		15.00	1.4	852
		16.00	1.44	850
		17.00	1.18	980

DISCUSSION AND CONCLUSION

From this limited set of sampling data, this preliminaries observation and conclusion can be deduced:

- Inconsistent distribution of vibration level from turbine driving end towards generator driving end.
- Variation of output power generated due this vibration distribution
- Need to take into account other factors such as flow rate and sediment contents at the intake side.

In order to have more precise and clear picture on how the developed vibration had affected the generated output power as well as on the damaged of turbine blades, further works will be expanded covering the following:

- Large number set of data covering different seasons (dry, wet and normal season). Data will be periodic and in continuous mode. This can be achieved via multipoint transducer mounted all axes and data is stored in data logger
- Further analysis using FFT modules available in VIBSCANNER analyzer. This is to study variation of frequency spectrum related to vibration level formed at the turbine and generator
- Trending of vibration spectrum of vibration at both measured machine using OMNITREND software.

This will help to identify root cause of the vibration development and distribution throughout this hydro system

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REFERENCES

- [1] H. Sharma and J. Singh, “Run off River Plant: Status and Prospects”, International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN: 2278-3075, Volume-3, Issue-2, July 2013.
- [2] S. Singh and M.P Upadhyay, Study of Different Issues and Challenges of Small Hydro Power Plants Operation”, IEEE, International Conference on Advances in Energy Conversion Technologies (ICAECT), pp 88 – 91, 23 – 25 January 2014.
- [3] S.A.O. Ilupeju and F.L. Inambo, “Potential of Small Hydro Power in South Africa: The Current Status and Investment Opportunities,” IEEE, Domestic Use of Energy (DUE), Proceedings of the Twenty-Second, pp. 1-16, 2014.
- [4] Jean-Claude Sabonnadiere, “Renewable Energy Technologies,” ISTE Ltd and John Wiley & Sons, Inc., ISBN: 978-1-84821-135-3, 2009.
- [5] A. Harvey, A. Brown, P. Hettiarachi and A. Inversion, “Micro-Hydro Design Manual: A guide to small-scale water power schemes,” Practical Action Publishing, ISBN: 978-1-85339-103-3, 1993.
- [6] M.F. Basar, A. Ahmad, N. Hasim and K. Sopian, “Introduction to the Pico Hydro Power and the Status of Implementation in Malaysia”, IEEE Student Conference on Research and Development, 2011.
- [7] “World Small Hydropower Development Report 2013,” www.smallhydropowerworld.org, 2013
- [8] R. Gwilliam, “Hydro Electricity,” Course at Centre for Alternative Technology (CAT), Powys, Wales, 9 – 14 December 2014.
- [9] “Final Report Renewable Energy Technology Roadmap,” Malaysia Industry Government Group for High Technology, 2010.
- [10] “Malaysia Report on Small Hydro Power (SHP),” Malaysia Industry Government Group for High Technology, 2012.

- [11] K.G. Ranga Raju and U.C. Kothiyari, "Sediment Management in Hydroelectric Projects", Ninth International Symposium on River Sedimentation, Yichang, China, 18 – 21 October, 2004.
- [12] Pratik Man Singh Pradhan, "Improving Sediment Handling in Himalayas", OSH Research, Nepal, October 2004.
- [13] <http://www.ni.com/tutorial/13042/en/>
- [14] G. Boyle. Renewable Energy: Power for a Sustainable Future, 2nd ed. Oxford, UK: Oxford University Press, 2004
- [15] http://www.daviddarling.info/encyclopedia/T/AE_Turgo_turbine.html
- [16] http://energyeducation.ca/encyclopedia/Turgo_turbine
- [17] Charles Van Loan, Computational Frameworks for the Fast Fourier Transform (SIAM, 1992).
- [18] Heideman, M. T.; Johnson, D. H.; Burrus, C. S. (1984). "Gauss and the history of the fast Fourier transform". IEEE ASSP Magazine. 1 (4): 14–21. doi:10.1109/MASSP.1984.1162257.
- [19] Strang, Gilbert (May–June 1994). "Wavelets". American Scientist. 82 (3): 253. JSTOR 29775194.
- [20] Dongarra, J.; Sullivan, F. (January 2000). "Guest Editors Introduction to the top 10 algorithms". Computing in Science Engineering. 2 (1): 22–23. doi:10.1109/MCISE.2000.814652. ISSN 1521-9615.
- [21] <https://www.pruftechnik.com/products/condition-monitoring-systems/portable-systems-for-condition-monitoring/vibscanner.html>
- [22] <https://www.pruftechnik.com/products/condition-monitoring-systems/condition-monitoring-software/omnitrend.html>.