ICSV14

Cairns • Australia

9-12 July, 2007

14th International Congress on Sound & Vibration

THE INVESTIGATION OF SUBMERGED VERTICAL PUMPS IN A POWER PLANT USING VIBRATION BASED CONDITION MONITORING TECHNIQUE

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Abstract

Condition monitoring has received considerable and wide attentions through most of the industries employing rotating machinery. It is increasingly becoming vital in industry because of the needs to prolong the machine life, increase reliability and decrease possible loss of production due to faulty machines. Vibration monitoring is the most popular technique, given its direct ability to detect and diagnose faults in machinery, which it is typically found in large industries such as oil and gas, petrochemical and power generation plant. This paper presents the field investigations of submerged vertical pumps with suspected cavitation in a power plant. Frequent impeller failures of submerged vertical pumps would potentially result in the total plant shutdown without warning. Vibration analysis was undertaken on the pump of concern in assist plant personnel in making decision on its operations. The predictive condition monitoring for the pump in the investigation include the vibration monitoring and a simple statistical analysis based on monthly overall vibration level, which is useful for reasonably accurate diagnosis in actual commercial pump in power plant. High frequency vibration was shown to be a good indicator of cavitation. It was shown that the investigations implied a wrong setting of the adjusting screw caused the large gap between the impeller and the casing and therefore enabling the seawater to slip back to the pit and hit the impeller and also the pump operating conditions that had resulted to the impeller failures.

1. INTRODUCTION

Vibration in rotating machinery is an extremely important consideration and typically found in the industries such as oil and gas, petrochemical and power generation plant. The investigation has been done at one of the power plant of an Independent Power Producer (IPP) in Malaysia, upon which the vibration analysis and data monitoring have been observed in two submerged vertical pumps (referred herein as CWP1 and CWP2). The pump is used for pumping of cooling water to the condenser. The power plant has 2 units of gas turbines with an additional unit steam turbine, operating as a combined cycle plant with steam generation from waste heat recovery boiler. The total power generation output is 330 MW. The occurrence of vibrations in these pumps in particular results to economic repercussions associated with downtime and inability to operate the machines at full load or rated speed.

Condition monitoring is an underpinning technology in implementing predictive maintenance [2]. The predictive condition monitoring for the pump in the investigation include the vibration monitoring (the procedure comprises data acquisition, signal processing, condition assessment and decision making [2,4]) and developing the statistical analysis overall alarm level. The vibration monitoring is undoubtedly the most effective technique to detect mechanical defect on the pumps. This can be done by vibration analysis to determine the operating and pumps condition [3]. Spectrum analysis is used to detect and identify the problem in the pump. A suggested analysis technique of statistical analysis overall alarm level is developed is one of a series in the continuous condition monitoring for the pumps. This method obviously to give some form of warning of trouble before it happens. The plant personnel will then attempt to assess if the vibration level is acceptable based on manufacturer’s recommended limit and some other vibration criteria as recommended by various standards [6]. This may simply to allow the plant personnel to maintain the pump operation during schedule before it breaks down and stops operation. Measurements can be extrapolated in order to predict when unacceptable vibration level be reached and when the pumps must be serviced. This is also called a trend monitoring and allows the engineer to plan for repairs well in advance.

The pumps were identical and installed in parallel connected to a common header after discharge routed to the condenser. The pumping medium is seawater. The impeller of each pump has 4 blades and the pump vertical shaft supported on sleeve bearings located in an inner tube in the riser tube. The drive shaft is approximately 10.5 meters from the sea level. Table 1 shows the pump main specification for submerged vertical pumps.

Table1. Pump specification.

Flow Capacity	Speed	Total Dynamic Head (TDH)	Specific Speed (Ns)
13800m^3/hour	585 RPM	16.2 m	8500

This paper reports on vibration faults in pumps, vibration monitoring and a simple statistical analysis based on monthly overall vibration level were assessed and presented. It was to find out the abnormal vibration problem, fault diagnosis on both pumps has been performed. Failures in submerged vertical pumps due to vibrations can be prevented if visually monitored and addressed accordingly.

2. NATURE OF PROBLEM IN THE SUBMERGED VERTICAL PUMPS

CWP2 is used as the baseline for fault diagnosis based on the assumption that this pump had been operating trouble free and in good condition since its replacement in year 2002. Ever since this pump replacement, minor cavitation was suspected based on visual evidence from pitting of impeller blades during periodic maintenance, this unit had however operating without trouble till date. Since prior baseline measurements were not available, a comparison between these two pumps was undertaken with the intent of comparing vibration spectrum of the pump of concern (CWP1). This was deemed a good approach since both pumps were identical and operating at a similar running speed (585 rpm). The pump CWP1 is more problematic as they had been unscheduled breakdown failures for a few times due to a broken impeller and had been an issue of concern to the plant. The pump vendor recommended a new impeller with a revised design at a reduced trailing edge on the impeller blades. The pump with revised design was installed in September 2005. After one month of operation, some peculiarities were noticed in CWP1. From site observation during high vibration incident, knocking sound was clearly audible from the pump CWP1. Cavitation was suspected since vibration levels were excessively high and could be observed from the vibration spectrum in the next section. The vibration level was reported to be more day by day. The new impeller of revised design as fitted to CWP1 was immediately removed and a refurbished (original) impeller was fitted back in October 2005. The refurbished impeller failed again in April 2006. A totally new impeller replacement with the original design was fitted in May 2006 and was operate till date, with the event that the pump CWP1 was sustained high vibration levels until remedy root cause of the problems were identified.

There are currently no flow measurement devices on the pumps, and came fitted with analogue pressure indicator on the common discharge pipe only. Therefore, vibration based condition monitoring technique were presented to help in identification of the root cause and to access if the vibration level is acceptable as recommended by Berry's paper [6], in such a manner improved pumps reliability and plant availability.

3. CONDITION MONITORING IN THE SUBMERGED VERTICAL PUMPS

Condition monitoring means that every machine is regularly subjected to a 'health check' – normally with a vibration inspection: in the simplest case, the measurement instrument which is used to perform this check provides a numerical value which can be compared with a standard value to indicate the machine states, good - fair – bad.

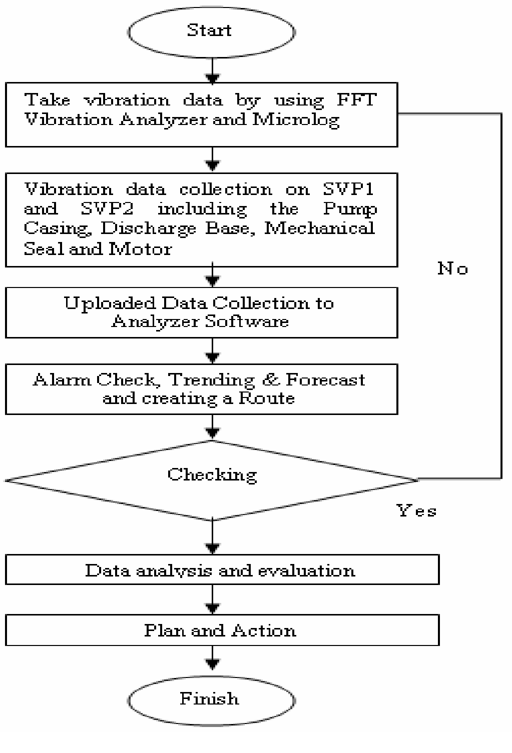

Figure 1. Condition monitoring flow chart.

Excessive vibration means, increased wear, increased wear, increased repair effort, bad product quality and higher energy consumption. By doing a good condition monitoring the maintenance events can be scheduled in an orderly fashion and allows for some lead-time to purchase part for necessary repair work and thus reducing the need for large inventory spares for the machine.

Vibration measurement is an effective, on-intrusive method to monitor pumps condition during startups, shutdown and normal operation. Vibration equipment used to collect the vibration data was FFT vibration analyzer. The collection of vibration data then uploaded to the Analyzer Software. Data collections on the pumps are include the pump casing, discharge base, motor and mechanical seal and etc in various directions to identify and investigate the main problem in the pump.

4. VIBRATION SPECTRUM ANALYSIS

Vibration measurements were undertaken on both pumps CWP1 ands CWP2. Vibration spectra of the respective pumps were measured and assessed. Since prior baseline measurement were not available, a comparison between both pumps were undertaken with intent of comparing vibration characteristics of the pump CWP1 with the pump that was regarded fairly good condition of the pump CWP2.

For each operating condition of the pump both acceleration and velocity signals were acquired and analyzed with the sensors located at several positions (radial, axial, and transverse directions) with the purpose of selecting the most appropriate signals. For example For this reason of acceleration and velocity signals of the pump casing have the same potential interest, even though they also reflect the vibrations of the surrounding structures which are mechanically coupled to the pump casing. The parameter signal at the pump casing was measured in three orthogonal directions [5], after proper flattening of some zones of the casing surface.

Figure 2 to Figure 5 showed a series of comparison between vibration data taken from CWP1 (bad pump) for the revised impeller design and good CWP 2 (original design), measured in vibration velocity and acceleration spectra.

4.1 Discharge base (axially)

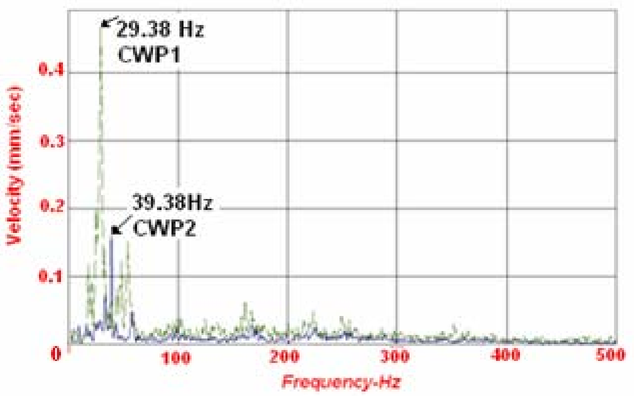

Figure 2. Velocity Spectrum (0- 500Hz).

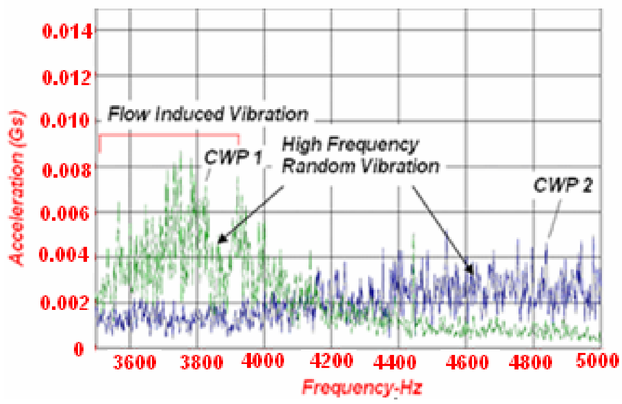

Figure 3. Acceleration Spectrum (3500-5000 Hz).

The velocity spectra (0-500 Hz) with the highest amplitude (0.468mm/sec) of the CWP1 showed in the vibration response peak at 29.38 Hz (- 3x rpm) and the highest amplitude (0.162 mm/sec) of the CWP2 in the response peak at 39.39 Hz (~4x rpm). The bad pump CWP1 demonstrated high vibration response peaks compared to good pump CWP 2. The blade passing frequency at 4x rpm, although of lower amplitudes as compared to the bad pump, was present in the good pump CWP2.

The acceleration spectra as shown in Figure 3 with the zoom spectra (3500-5000 Hz) where the bad pump CWP1 has the higher frequency random vibration and high peak vibration amplitude as compared to good pump CWP2. The spectral analysis demonstrated that overall acceleration (G's) for CWP1 was 0.17 G's and CWP2 was 0.095 G's. This indicates that from the overall acceleration of the CWP1 and high amplitude frequency harmonics shows the bad condition of the pump rather than the CWP2. The high frequency random vibration is often associated as characteristics of cavitation and flow turbulence in the pump [1]. Cavitation might excite high frequency structural resonances and maximum amplitudes appear as sharp spikes. Between these spikes are low amplitudes, smooth and rounded peaks. An examination comparison of the velocity spectrum indicates that the CWP1 were significantly had higher vibration level as compared to good CWP2 with the overall vibration velocity for CWP1 was 0.961 mm/sec and 0.304 mm/sec for good CWP2. The measurements therefore confirmed the presence of cavitation and flow induced vibrations.

4.2 Mechanical seal (axially)

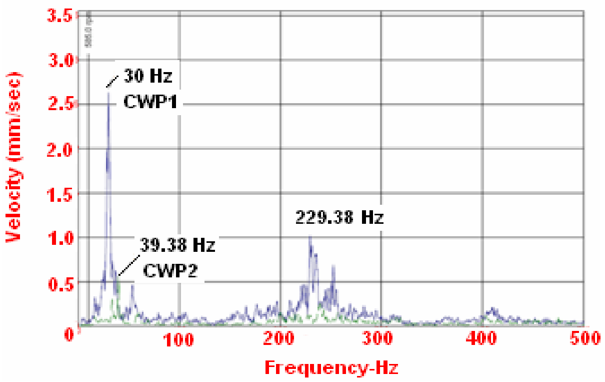

Figure 4. Velocity Spectrum (0- 500Hz).

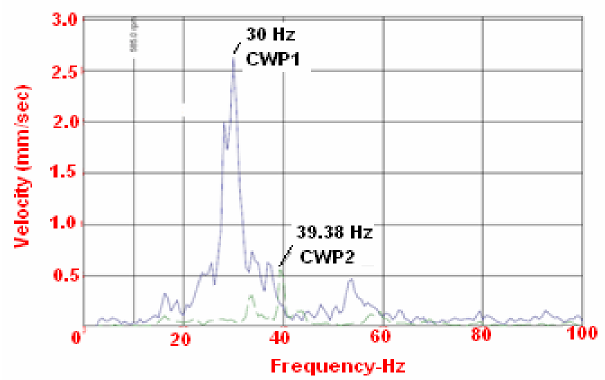

Figure 5. Velocity Spectrum (0- 100Hz).

Vibration velocity spectra measured on the mechanical seal in the axial direction are depicted in Figure 4 and Figure 5. The vibration velocity spectra (0-500Hz) showed an increased velocity response peaks at 30 Hz (3x rpm) with the amplitude of 2.63 mm/sec while Figure 5 showed the zoom spectra (0-100Hz). The overall vibration velocities of the pump CWP2 was less pronounced and significantly lower (1.489 mm/sec) as compared to pump CWP1 (5.955 mm/sec). The resonant frequency of 30 Hz for the inner tube (holding the shaft) within the riser tube as excited by the flow was particularly evident.

4.3 Pump casing (horizontal)

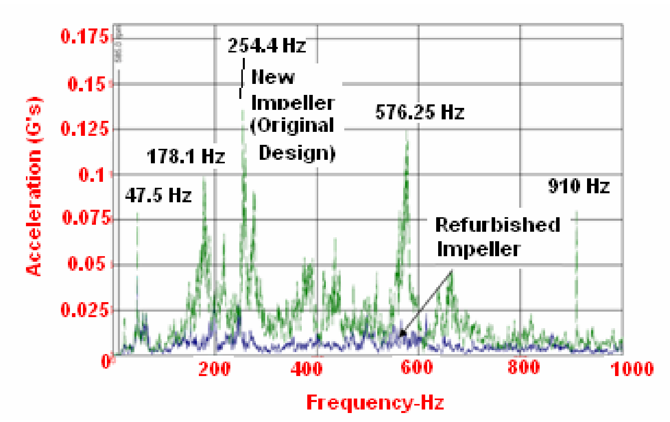

Figure 6. Acceleration Spectrum (0-1000 Hz).

Figure 6 presents typical comparisons of measured vibration spectrum comparing to the new impeller and refurbished impeller (original design) in the same pump (bad pump SVP1). New impeller (original design) shows the high vibration amplitude response compared to the refurbished impeller. Spectral analysis showed that higher flow excitation to the pump casing with the new impeller (original design) was evident.

The overall acceleration for new impeller (original design) was 0.860G's and refurbished impeller was 0.241G's. The erratic trending pattern of the vibration response clearly showed the new impeller (original design) when both units put in service characterize as appearance of boarder vibration frequency components associated with flow excitation as compared to refurbished/old impeller.

During the major overhaul recently, it was found out that the investigation implied a wrong setting of the adjusting screw caused the large gap between the impeller and the casing and therefore enabling the seawater to slip back to the pit and hit the impeller that had resulted to the impeller failures. And apart of this, it can be explained that the present of vibration peak at 30 Hz was caused by the large force impact on the impeller and the riser tube itself, causing it to vibrate excessively. Besides that, the pump operating conditions could also contribute to relatively more severe cavitation in the pump. Now, the pump CWP1 is operating at the normal condition with a fairly good overall vibration level at 4.0 mm/sec as could be assessed from the control room.

5. MONTHLY STATISTICAL OVERALL ALARM FOR ASSESSING THE PUMPS CONDITION

The pump has been put in service and repaired for several times but had no prior detail of vibration data for pumps diagnosis. For purpose of detailed analysis of the diagnosis of both pumps (CWP1 and CWP2), several steps to develop the monthly statistical overall alarm has been made obviously to obtain a trend in vibration characteristic that can warn of impending trouble, so it can be reacted upon before the failure occurs, upon which the plant personnel can plan for the further action of the scheduled maintenance task. Several steps to develop the monthly statistical overall alarm are performed such as; (i) collected and store the daily vibration level in a month. (ii) averaging all the monthly vibration data. (iii) calculate a standard deviation overall vibration level. (iv) calculate a monthly statistical overall alarm. It can be formulated as follows:

Average overall vibration data;

$$X_{AVE} = \frac{X_1 + X_2 + X_3 + X_4 + \ldots + X_n}{N} \tag{1}$$

Standard Deviation Overall Vibration Level;

$$S = \sqrt{\frac{(X_1 - X_{ave})^2 + (X_2 - X_{ave})^2 + \ldots + (X_3 - X_{ave})^2}{N-1}} \tag{2}$$

Statistical Overall Alarm;

$$SOA = X_{AVE} + 2\,S \tag{3}$$

where N is Number of vibration data, X is Velocity vibration level, X_{AVE} is Average Velocity vibration level, S is Standard Deviation and SOA is Statistical Overall Alarm.

Monthly statistical overall velocity vibration level was undertaken at pump Y-axis for both pumps (CWP1 and CWP2) and as shown in Figure 7. The result as shown in the graph is to determine and identify the trending of the monthly overall vibration velocity level for maintenance and condition monitoring purposes. This data was obtained from the on-line monitoring system that takes the vibration signal from the radial direction accelerometer installed on submerged pump housing.

A common dilemma for plant personnel and engineer is to determine whether the vibrations are acceptable to allow further operation of the machine in the safe manner. To solve the dilemma it is important to implement the vibration checks to detect defect at an early stage. The effective value of the vibration velocity is used for assessing the pumps condition. In order to monitor the condition of a pump, it is usually only necessary to measure characteristic parameters of the vibration velocity. Table 2 used to give a standard of “Overall Condition Rating” based on the overall vibration level and is mainly for Vertical Pumps [6].

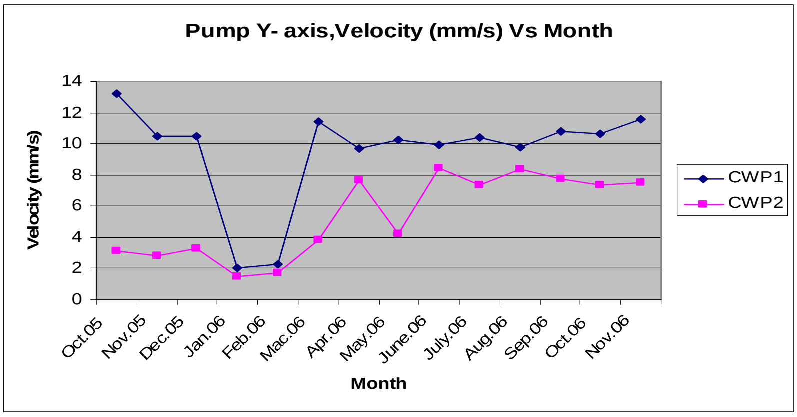

Figure 7. Overall vibration Level at Pump Y-axis.

The column entitle "Good" and "Fair" are used to give an machine an overall condition rating based on the highest overall vibration level found on the pump measurement point. These rating also applied with alarm limit where the pump are suggested to operate above Alarm1, but will likely fail prematurely if problems are not identified and corrected. While the pump operates above Alarm 2 may suffer catastrophic failure.

Table 2: Criteria for overall condition rating (overall velocity, Peak Overall Velocity in mm/sec) [12].

Criteria	Good	Fair	Alarm 1	Alarm 2
Peak overall velocity (mm/sec)	0 - 8.249	8.249 - 12.69	12.69 - 19.036	Above 19.036

Table 3: Data for monthly statistical overall vibration level criteria for CWP1 and CWP2 (Pump Y-axis) operating in parallel mode.

Month	CWP1			CWP2		
	mm/sec	Criteria	Remark	mm/sec	Criteria	Remark
Oct. 05	13.23	Alarm1	New impeller (Different design)	3.13	Good	Original impeller design. Pump is running in series (one pump operation) in January and February 2006.
Nov. 05	10.46	Fair	Use refurbished (original impeller, Nov 05-April 06). Pump is running in series (one pump operation) in January and February 2006.	2.81	Good	
Dec. 05	10.47	Fair		3.28	Good	
Jan. 06	2.01	Good		1.46	Good	
Feb. 06	2.28	Good		1.74	Good	
Mac 06	11.43	Fair		3.80	Good	
Apr. 06	9.729	Fair		7.69	Good	
May 06	10.25	Fair	New impeller (original design, May 05-Nov 06).	4.25	Good	
June 06	9.92	Fair		8.43	Fair	
July 06	10.39	Fair		7.38	Good	
Aug. 06	9.78	Fair		8.39	Fair	
Sep. 06	10.82	Fair		7.76	Good	
Oct. 06	10.62	Fair		7.31	Good	
Nov. 06	11.60	Fair		7.53	Good	

Table 3 represents a monthly statistical overall vibration level criterion for CWP1 and CWP2 (Pump Y-axis). The data is for both pumps running in parallel. A new pump replacement for pump CWP2 in 2002 with an original impeller design had a low vibration level compared to pump CWP1. According to the history of the operating pump a new impeller of different design (different shape compared to original impeller) was installed in

September 2005 at CWP1. Almost immediately upon operation of the CWP1, cavitation was evident as captured in the vibration spectrum as mentioned in the previous section since vibration level excessively high with a corresponding rattling noise sound from the pump clearly audible. The new impeller (different design) as fitted to the CWP1 was immediately removed in end of October 2005 and the refurbished (original impeller) was replaced after the overall vibration level reach the “Alarm 1” with 13.233 mm/sec. On January 2006 and February 2006 the power plant had using just one pump operating at one time (pump running on series) that had extremely reducing the overall vibration level on the month. The refurbished (original impeller) impellers yet failed in 21 April 2006 and cause the entire plant shutdown. Due to the criticality of the CWP1 the plant personnel and the senior management of the plant should purpose a scheduled shutdown and rapid service action since the overall vibration level obviously increase very high suspected end of Mac 2006.

From the investigation, based from the overall condition rating for pump CWP1 was under category “Fair” condition and for CWP2 was in “Good” condition. Mechanical and operational conditions of the machine (pumps) should periodically monitor and when unhealthy trends are detected, vibration diagnosis of the pumps were then identified and scheduled for maintenance. The pumps would then be shut down at a time when it is most convenient, in this case the suggested overall vibration value shall not exceed 13 mm/sec, therefore the damaged components would be replaced. If left unsolved, this failure could result in costly secondary failure.

6. CONCLUSIONS

Condition Monitoring is probably the most important tool in these pump problem and has become accepted and proven worldwide in various industries. They are various ways to monitor the pumps but most commonly and effectively are by doing a vibration monitoring. A continuous inspection and analysis due to the machine is the best solution to control and increase the operation of the pumps. Inappropriate condition monitoring and prediction will reduce the pump performance, increase damages; inappropriate maintenance schedule and most importantly increase cost. The investigation clearly implied a wrong setting of the adjusting screw caused the large gap between the impeller and the casing and therefore enabling the seawater to slip back to the pit and hit the impeller and also the pump operating conditions that had resulted to the impeller failures. High frequency random vibration was shown to be good indicator for flow induced vibration and cavitation detection. Based on the measurement, spectrums analysis, statistical overall alarm and the standard of vibration monitoring confirmed the better condition of the CWP2 compared with the CWP1.

REFERENCES

[1] C.Z.Tan, M.S. Leong, Y.C.Lee, “Field Investigation of Cavitation and Flow Induced Vibrations in Submerged Vertical Pump in a Power Plant”, *Proceedings of WCEAM*, 2006, Australia, pp. 1192-1201.

[2] S.Zhang, L.Ma and J.Mathew. “Vibration Feature Analysis for Rolling Element Bearing Diagnosis Using Bayesian Neutral Networks”. *Asia Pacific Vibration Conference 2005*, pp 373-378.

[3] Malcolm k Graham, Barry nurcombe, CEng. “Vertical water pumps –what’s happening down the hole?”

[4] ByeongKeun Choi, HackEun Kim, ChangRim Choe and Bo-Suk Yang, “Vibration Diagnosis of High Pressure LNG Pumps”. *Asia Pacific Vibration Conference 2005,* pp 168-173.

[5] Jorge L. Parrondo, Sandra Velarde and Carlos Santolaria, “Development of a predictive maintenance system for centrifugal pump”. *Journal of Quality in Maintenance Engineering,* Vol **4** No 3 198-211 (1998).

[6] J.E. Berry, “ *How to implement an effective condition monitoring program using vibration analysis”*, Technical Associates of Charlotte Inc, 2001.