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Research Article

Clogged Impeller Diagnosis in the Centrifugal Pump Using the Vibration and Motor Current Analysis

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Abstract. The impeller-clogging phenomenon in centrifugal pumps is such a kind of the fault that leads to increase the vibration and reduce the performance of pumps. In addition, impeller-clogging could make some problems in the production process of factories. This research assigns to the detection of clogged impeller in a centrifugal pump using the vibration and motor current analysis. In this research, a test rig is set up and one of the impeller's passageways is clogged by the sealing tape. The clogging detection, based on the vibration analysis, is done using the Fast Fourier Transform (FFT). The obtained results show that the dominant frequency in the impeller-clogging phenomenon is the rotational frequency of impeller (1xRPM). The measuring vibration values in three directions (horizontal, vertical, and axial) show that the clogged impeller has more effects on the axial vibration responses. Furthermore, in this case, the electrical current consumption of electromotor is reduced.

Keywords: Centrifugal pump; Clogging; Vibration analysis; Motor current analysis.

1. Introduction

During the past decades, due to the factories' need for surviving in competitive environment and keeping economic production while enhancing safety factor, maintenance strategies have been revised frequently. In the past, the preventive maintenance was the most important strategy set forth by maintenance managers. However, due to the aforementioned reasons, this strategy was evolved to predictive maintenance which is also known as condition-based maintenance. Centrifugal pumps are among the most important equipment that are widely used in various industries. In these equipment, timely detection of faults can play a very important role in enhancing the production level and practicing the safe production. In the present research, an attempt is made to detect clogging in the impeller of a centrifugal pump using vibration analysis and electromotor current signature analysis methods. Numerous factors (e.g. misalignment, more clearance, leakage, clogging along piping and impeller's eye, and electrical problems) contribute to vibrations and defects in pump components, eventually reducing the pump efficiency. As such, timely identification of these defects and eliminating them will largely contribute to reduced cost and increased productivity. There are various methods for the fault detection in centrifugal pumps, of which one can refer to vibration analysis, noise analysis, electromotor current analysis, oil analysis, thermography, etc. Currently, the vibration analysis and the electromotor current signature analysis are the most widely applied methods in this regard. The impeller clogging of pumps may occur due to various reasons, of which the most important ones include the entrance of external objects and material sedimentation at the impeller. In case of impeller clogging, a fraction of its useful space for pressurization and

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fluid transmission is lost, and not only some vibrations are generated, but also pump performance is disturbed while affecting the consumed electrical current and obtained waveform as well.

The use of vibration analysis as a suitable tool for maintaining and monitoring the status of machineries was developed and adopted since early 1970s. Later on, electromotor current signature analysis was also used for fault detection purposes. Essentially, a similar approach is followed to detect failure in these two methods. In these two methods, frequency spectrum analysis is among the most popular techniques. In 1978, Adams *et al.* [1] showed that the presence of failure in components tends to reduce their natural vibration frequency. Later in 1980, Taylor [2] demonstrated that bearing failure can be detected using vibration spectrum analysis. In 1987, Thomson *et al.* [3] was the first to use electromotor current signature analysis for fault detection in the rotor of a three-phase induction electromotor. Subsequently, in 1988, Kliman *et al.* [4] succeeded to detect rotor bar failure and eccentricity of air gap in a three-phase induction motor. In 1994, Kasada [5] undertook studies on reduced efficiency of a pump using vibration analysis, pressure pulsation, and motor power measurement. He observed that instability in the motor power results from instabilities in hydraulic conditions of the pump. In 1994, Thomson and Reith [6] studied the effect of velocity fluctuations on the electrical current and further used experimental results to find that, whenever velocity changes occur, some side bands are observed around the rotation speed in the frequency range. They showed that these side bands are generated when a misalignment exists with their height increased with increasing the misalignment. In 1996, Kasada [7] detected a functional fault in a part of its load (designed flow rate), which was due to clog of the pump filter) using electromotor current analysis. In 2000, Rao [8] illustrated that bearing faults can be detected using vibration analysis. Later in 2001, Wang *et al.* [9] used the analysis of vibration frequencies to detect gear defects. Kenull *et al.* [10] determined the velocity of a floating motor by using current analysis in 2003. In 2008, Kar and Mohanti [11] practiced the application of Fourier transform and wavelet conversion in electromotor current analysis for fault detection on gears. Moreover, Mohanti *et al.* [12] could detect rotor fault in a centrifugal pump using vibration analysis and electromotor current analysis in 2012. In 2014, Al-braik *et al.* [13] found that the defect on the tip of impeller could be detected by vibration analysis. In the same year, Hamomd *et al.* [14] used a new method based on the Modulation Signal Bispectrum analysis (MSB) for diagnosing the inlet vane defect and the exit vane fault from the healthy impeller. Moreover, Tian *et al.* [15] used MSB analysis to reveal the weak nonlinear characteristics of current signals when the pump with different impeller faults operates under a wide range of flow conditions. They showed that two static features including the amplitude at supply frequency and the frequency value of bar-passing frequency could be based on to diagnose impeller defects on exit vane tips and inlet vane tips. In addition, the dynamic parameter of sidebands at vane-passing frequency could also be a good indicator for differentiating between the faults. In 2017, Hamomd *et al.* [16] used MSB method in order to develop a feature set for detecting and diagnosing faults from both the bearings and impellers in a centrifugal pump. They showed that the diagnostic features developed by MSB allowed impellers with leakage and blockage, and bearing outer-race faults could be identified under different operating conditions. In the past, numerous studies have been performed on fault detection in rotating machines. To the best author knowledge, the impeller-clogging phenomenon has been investigated very limitedly [16]. Given that impeller clogging may occur in any centrifugal pump, it is very important to detect it in a timely fashion.

In the present research, firstly, vibrations and electromotor current signature of a healthy pump were analyzed. Afterwards, inducing some blockage at impeller eye in one passageway, its effects on the pump vibrations and electromotor current signature were investigated. In order to measure electromotor current signature, a device with the capability to measure changes in the magnetic field as a result of changes in the current was used. Impeller clogging was implemented by a sealing tape. The vibrations were recorded and then interpreted by a portable vibration analyzer. Impeller clogging was practiced in one passageway of impeller. The used pump in the present research was a centrifugal pump with a closed impeller, overhung rotor and coupled with a three-phase induction electromotor.

2. Signal Processing by using Fourier Transform

2.1 Fourier Transform

In this research, vibration signal analysis was performed by transforming the time-domain signal to frequency-domain one using Fourier transform. Fourier analysis transforms a signal $f(t)$ from a time-based domain to a frequency-based one, therefore, generating the spectrum $F(\omega)$ that includes all of the signal's constituent frequencies (fundamental and its harmonics), which is defined as Eq. (1) [17].

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt \tag{1}$$

For example, in Fig. 1, an original signal is decomposed into its constituent signals.

2.2 Motor Current Analysis

Electromotor current signature analysis can be used as a monitoring method for pumps and other machineries. In this method, using a clamp and a convertor, changes in the magnetic field due to changes in the current are measured. Later on, in a similar way to the previous method, the obtained signal is subjected to Fourier transform. Finally, one can detect faults in the rotating equipment by investigating and comparing the obtained frequencies.

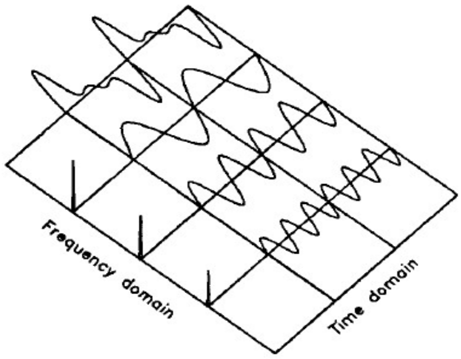


Fig. 1. Relationship between time domain and frequency domain [18]

3. Experimental Details

The pump which is used in the present research is a Weinmann centrifugal pump with a closed impeller coupled with a three-phase squirrel-cage induction electromotor (manufactured by Westinghouse Electric Corporation) operating at 2940 rpm, maximum power of 3 hp, and nominal current of 5 A. This equipment is used for calibration purposes in the measurement calibration unit at Bandar-e-Imam Petrochemical Complex (Iran). An overview of the examined pumping system is shown in Fig. 2. The studied impeller is a bronze-made closed one with 6 vanes of 180 mm in outer diameter (Fig. 3).

Fig. 2. WEINMANN centrifugal pump

Fig. 3. Bronze impeller with six vanes

Given that the impeller is six-vane, vane pass frequency is 294 Hz (obtained by multiplying the number of vanes by the rotation frequency (49 Hz)). In the present research, a vibration measurement device designated as VIBER-X5 is used with a VMI-192 accelerometer sensor (serial number: 1868). The sensor is manufactured by a Swedish company, VMI. Moreover, in order to measure the vibration signal, a special clamp is used which is capable of measuring the electrical field around a current-carrying wire. Data collection is performed at two points. One point on the electromotor close to the coupling, and another one on the bearing chamber close to the impeller. Data collection on the pump along the axial direction is demonstrated in Fig. 4.

Fig. 4. Vibration measurement

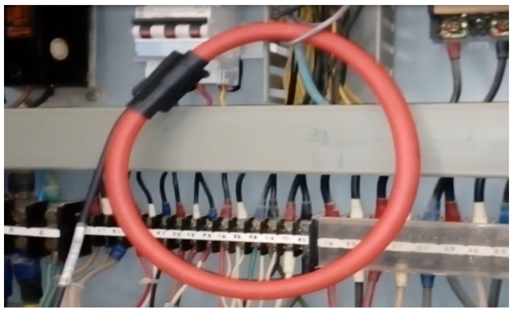


Fig. 5. AC flexible current probe

According to Fig. 5, measurement of the signal of the electric field resulted from the electromotor current is performed using a clamp meter along with the recorded signal sent to vibration measurement device. Subsequently, the vibration measurement device shows Fourier transform of the stored data. In addition, the electromotor current total values are measured by clamp ampere meter HIOKI 3280-10.

In this test, the pump with intact impeller is analyzed first by recording the vibration signal and the electromotor current graph. Later on, clogging in one passageway through the impeller is investigated and its effect on the vibration signal and electromotor current effect is studied. When clogging occurs inside the impeller's eye with no noise/friction inducing contact within the pump housing, the pump operates with widely open inlet and outlet. Therefore, the results are fairly affected by the impeller clogging and can be compared to normal conditions (prior to the clogging). The clogging is implemented using a sealing tape with negligible weight. Vibration measurements are performed at two points, one on the electromotor and one on the pump, with horizontal (H), vertical (V), and axial (A) measurements read at each point. Due to limitations in presenting all figures, only the figures related to Fourier transform of the measured vibrations and motor current signature on the pump are given.

4. Results and Discussion

Two experiments are performed in the present study: 1) pump vibration and electromotor current measurement when impeller is operating normally, and 2) pump vibration and electromotor current measurement when impeller is engaged with clogging of one passage way. The impeller without any blockage is shown in Fig. 6.

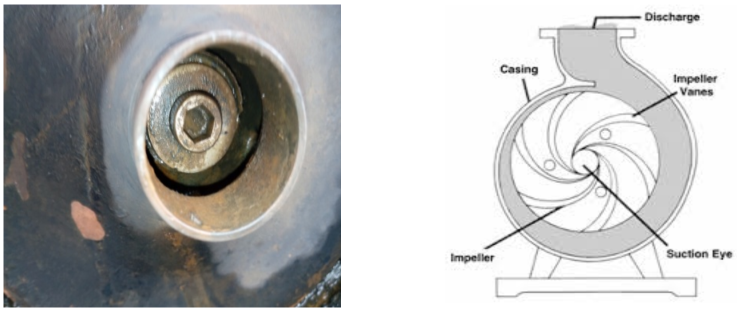
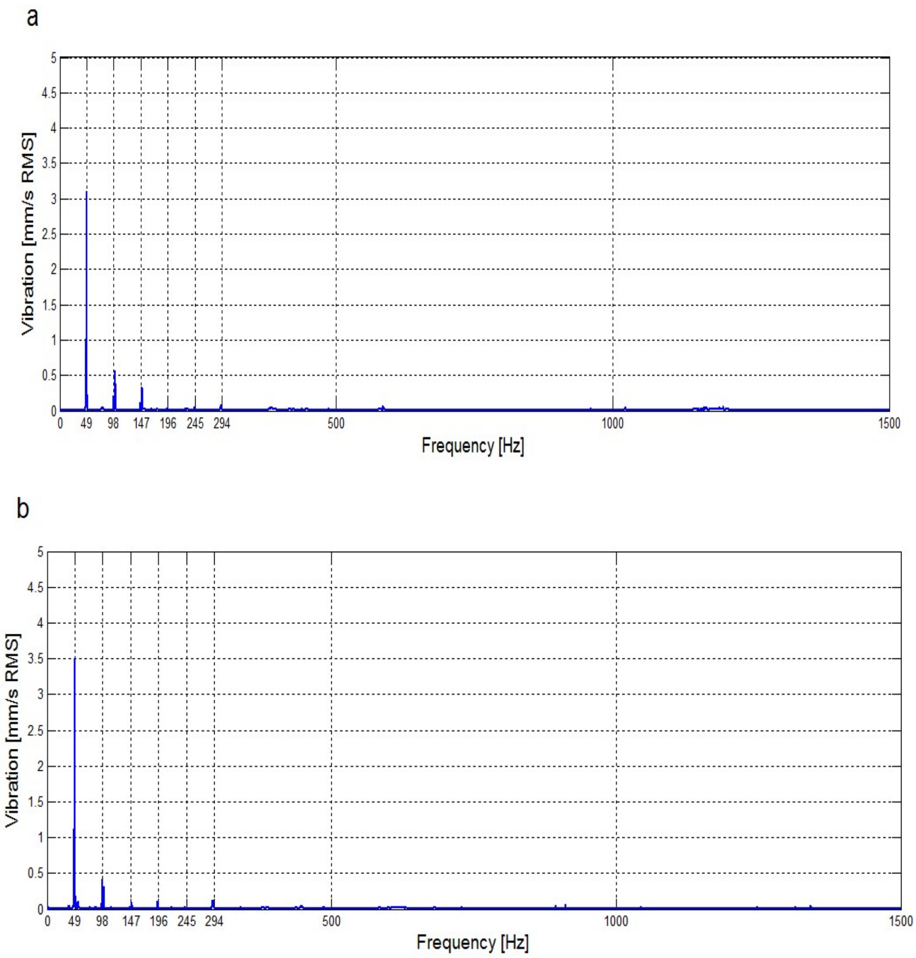


Fig. 6. Normal impeller

As shown, Fig. 7 indicates the frequency response of pump vibrations along the three primary directions when the impeller is operating normally (without any clogging).



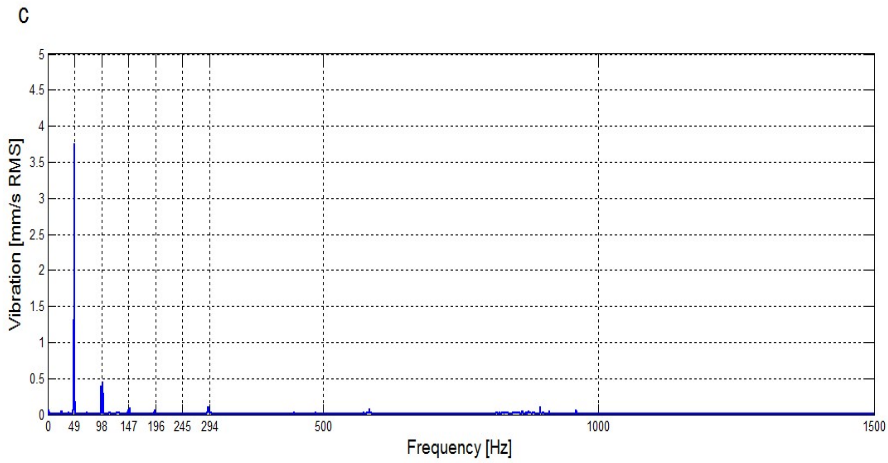


Fig. 7. Normal impeller vibration's FFT in the main directions (a). Horizontal. (b). Vertical. (c). Axial.

Table 1 reports the values of pump vibrations obtained when the impeller is operating with no clogging, for the six principle harmonics. As can be seen, Fig. 8 demonstrates Fourier transform of the signal obtained from the electromotor current. Amplitude of the waves at power grid frequency (50 Hz) is 94.55 dB. In this stage, the electromotor consumes power at 4.99 Amp.

Table 1. Pump vibrations along horizontal, vertical, and axial directions of the pump with normal (intact) impeller for frequencies of 1 to 6 times as large as principle frequency.

Frequency (Hz)	Horizontal mm/s RMS	Vertical mm/s RMS	Axial mm/s RMS	Observations
49	3.101	3.499	3.752	1X primary RPM
98	0.212	0.418	0.363	2X primary RPM
147	0.109	0.029	0.058	3X primary RPM
196	0.046	0.109	0.063	4X primary RPM
245	0.048	0.036	0.021	5X primary RPM
294	0.082	0.128	0.113	6X primary RPM (Vane Pass Frequency)

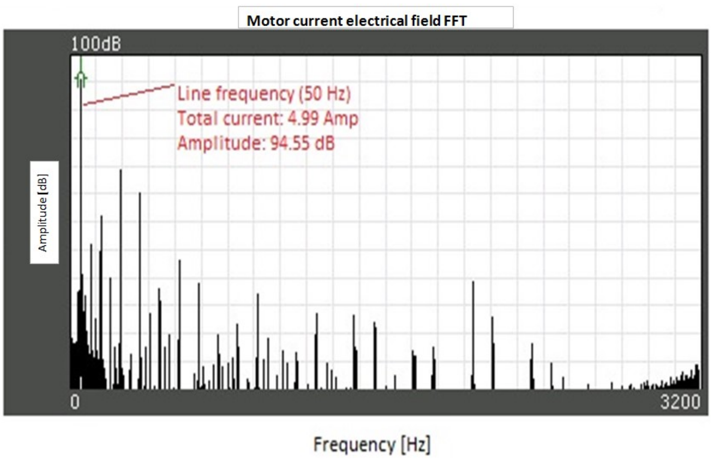


Fig. 8. Motor current FFT (pump with normal impeller).

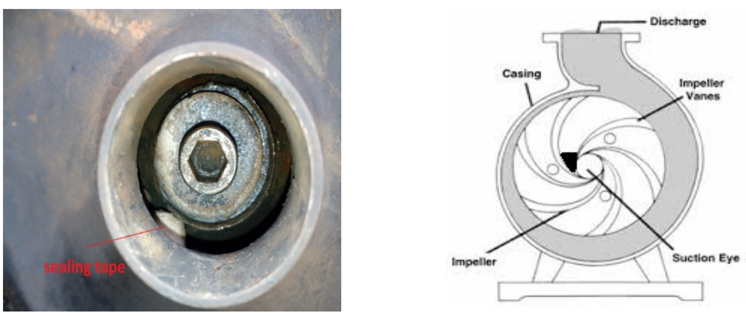


Fig. 9. Impeller clogging in one passageway.

The following figure (see fig. 9) shows the impeller with clogging in one passageway. As shown, Fig. 10 demonstrates the pump vibration signal and its Fourier transform in the second case, i.e. the impeller within one passageway clogging.

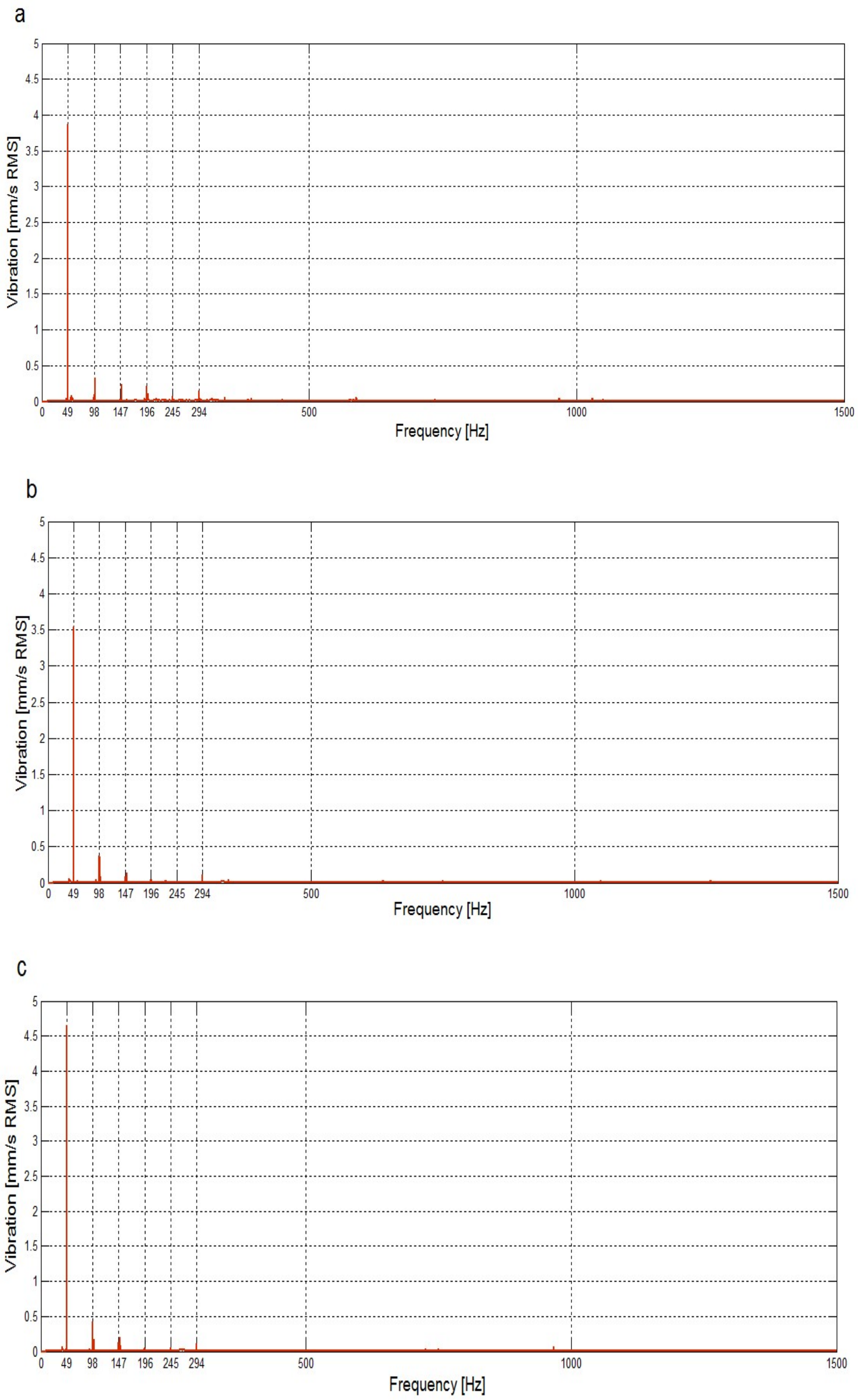


Fig. 10. Clogged impeller vibration's FFT in the main directions (a). Horizontal. (b). Vertical. (c). Axial.

Table 2 reports the values of pump vibrations in the second case, i.e. the impeller with one passageway clogged for the six principle harmonics. Fourier transform of the signal obtained from the electromotor current when the impeller is clogged in one passageway is demonstrated in Fig. 11. The amplitude of the waves at power grid frequency (50 Hz) is 98.80 dB. In this stage, the electromotor consumes power at 4.40 A. Table 3 details changes in vibration following the blockage. Maximum values reported in this table are those of the frequency equal to the pump rotation frequency. This frequency indicates faults, which in general, induce some imbalance in rotor.

Changes in vibrations in the first six harmonics are demonstrated in Fig. 12. In this Figure, it is observed that, due to the blockage phenomenon in the impeller, maximum fluctuations in vibrations are seen in the first harmonic (1 × RPM). Table 4 presents the consumed current by the electromotor in the first and second cases. It is seen in this table that, the impeller clogging has reduced the required current for pumping.

Table 2. Pump vibrations along horizontal, vertical, and axial directions for frequencies of 1 to 6 times as large as principle frequency of the pump with clogged impeller (one passageway is clogged).

Frequency (Hz)	Horizontal mm/s RMS	Vertical mm/s RMS	Axial mm/s RMS	Observations
49	3.864	3.534	4.657	1X primary RPM
98	0.093	0.378	0.423	2X primary RPM
147	0.036	0.086	0.130	3X primary RPM
196	0.216	0.044	0.044	4X primary RPM
245	0.076	0.026	0.056	5X primary RPM
294	0.142	0.117	0.116	6X primary RPM (Vane Pass Frequency)

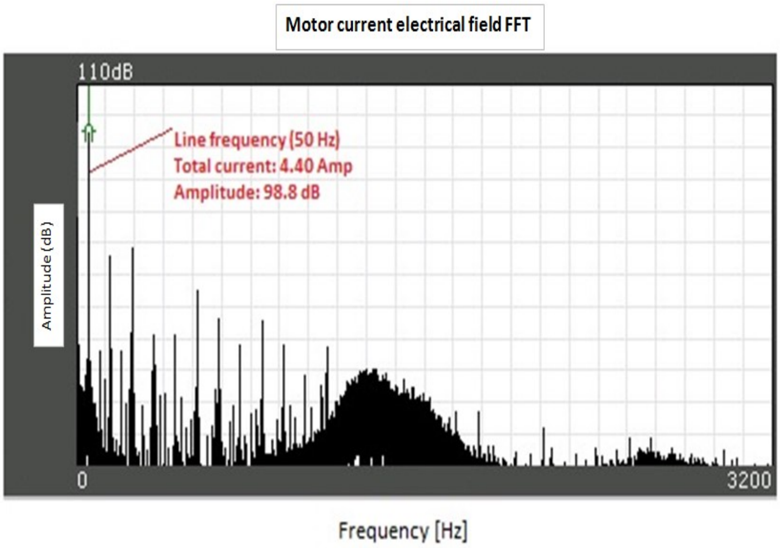


Fig. 11. Motor current FFT (pump with clogged impeller in one passageway).

Table 3. Absolute values of the differences in pump vibrations between the first and second cases along the three principle directions for the first six harmonics.

Frequency (Hz)	Horizontal mm/s RMS	Vertical mm/s RMS	Axial mm/s RMS	Observations
49	0.762	0.035	0.905	1X primary RPM
98	0.119	0.039	0.059	2X primary RPM
147	0.073	0.057	0.073	3X primary RPM
196	0.170	0.065	0.019	4X primary RPM
245	0.029	0.011	0.036	5X primary RPM
294	0.060	0.011	0.003	6X primary RPM (Vane Pass Frequency)

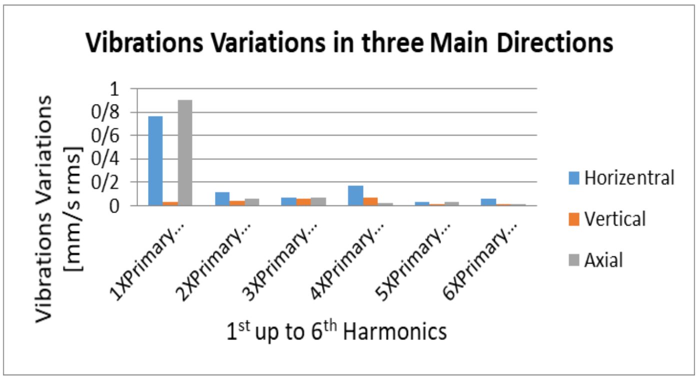


Fig. 12. Vibrations variations in three main directions

Table 4. Consumed current by electromotor in different cases.

Experimental cases	Current Amp. RMS	Percent of Nominal Current
Intact Impeller	4.99	99.8
Clogged Impeller	4.40	88

5. Conclusion

The main aim of this research was to investigate the impeller clogging in a centrifugal pump. For this purpose, firstly, pump vibrations and electromotor current effect were measured experimentally when the impeller was operating normally. Then, one of the passageway of the impeller's eye was clogged by a sealing tape and pump vibrations and electromotor current effect were measured when the system was operating at full capacity and the results compared to those of the previous case. The obtained vibration signal was analyzed using Fourier transform. Considering what was mentioned above, it can be concluded that frequency of the impeller clogging fault is equal to the pump rotation frequency. Moreover, in case of impeller clogging, the increase in the amplitude of vibrations is larger in axial direction rather than horizontal or vertical directions. Besides, given that a clogging tends to lower the current at which electromotor consumes power, a combination of increased amplitude of vibration at the frequency equal to the rotation frequency along with reduced amperage as an indicator of an impeller clogging were recognized. Since in the case of clogged impeller, a part of impeller did not participate to fluid transfer and flow rate became lesser than normal impeller, the electrical power consumption proportionally decreased.

References

[1] Adams, R. D., Cawley, P., Pye, C. J. and S. B. J., A Vibration Technique for Non-Destructively Assessing the Integrity of Structures, *Journal of Mechanical Engineering Science*, 20, 1978, 93-100.

[2] Taylor J.I., Identification of Bearing Defects by Spectral Analysis, *Journal of Mechanical Design*, Vol 102, 1980.

[3] Thomson, W.T., Chalmers, S.J. and Rankin, D., An online computer based condition monitoring system for rotor fault diagnosis in 3-phase induction motors, Turbo Machinery International, 28, 1987, 17–23.

[4] Kliman, G.B., Koegl, R.A., Stein, J., Endicot, R.D. and Madden, M.W., Non-invasive detection of broken rotor bars in operating induction motors, *IEEE Transaction on Energy Conversion*, 3(4), 1988, 873–879.

[5] Casada, D.A., Detection of pump degradation, presented at 22nd Water Reactor Safety Information Meeting, Bethesda, Maryland, and 24–26 October 1994.

[6] W. T. Thomson and D. L. Reith, *Online current monitoring to detect purely mechanical problems in three phase induction motor drives*, presented at the International Conference on Condition Monitoring, Swansea/UK, 1994.

[7] Casada, D.A. *Using the motors to monitor pump condition*, 4th NRC/ASME Symposium on Value and Pump Testing, Washington, DC/USA, 1996, 1–20.

[8] Rao J. S., *Vibratory Condition Monitoring of Machine*, New Delhi: Narosa Pub. House, CRC Press, 2000.

[9] Wang W. Q., Ismail F., and Golnaraghi M. F., Assessment of gear damage monitoring techniques using vibration *Measurements*, 15(5), 2001, 905-922.

[10] Kenull T., Canders W. R., and Kosyna G., Formation of self-excited *vibration* in wet motors and their influence on the motor current, *European Transaction on Electrical Power*, 13(2), 2003, 119-125.

[11] Kar C. and Mohanty A. R., Vibration and current transient monitoring for gearbox fault detection using multiresolution Fourier transform, *Journal of Sound and Vibration*, 311(1–2), 2008, 109-132.

[12] Mohanty A. R., Pradhan P. K., Mahalik N. P., and Dastidar S. G., Fault detection in a centrifugal pumps using vibration and motor current signature analysis, *Int. J. Automation and Control*, 6(3/4), 2012, 261-276.

[13] Al-braik A., Hamomd O., Gu F., Ball A., *Diagnosis of Impeller Faults in a Centrifugal Pump Using Vibration Signals*, Eleventh International Conference on Condition Monitoring and Machinery Failure Prevention Technologies, 10th - 12th June 2014, Manchester, UK.

[14] Hamomd O., Tian X., Chen Zh., Abdulrahman A., Gu F., Ball A., *A new method of vibration analysis for the diagnosis of impeller in a centrifugal pump*, 21st International Congress on Sound and Vibration, 13th - 17th July, 2014, Beijing, China.

[15] Tian, X., Feng, G., Chen, Z., Albraik A., Gu, F., and Ball A. The investigation of motor current signals from a centrifugal pump for fault diagnosis, Comadem 2014, 16th - 18th September 2014, Brisbane, Australia.

[16] Hamomd O., Alabied S., Xu Y., Daraz A., Gu F., Ball A., *Vibration based centrifugal pump fault diagnosis based on modulation signal bispectrum analysis*, In Automation and Computing (ICAC), 2017 23rd International Conference on, 1-5.

[17] Newland D. E., *An Introduction to Random Vibrations, Spectral & Wavelet Analysis*, 3rd ed., Dover Publications, 2005.

[18] Taylor, J., *The vibration analysis handbook*, Tampa: Vibration Consultants, 1994.