Investigate the Effect of Fan Configuration on the Performance of Aeration Units for Waste Water Treatment

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Abstract

Mechanical aerators play a vital role in sanitary drainage stations and affect reliability and performance of these stations. The mechanical aeration construction is rather simple as it only has a fan attached to a motor mounted on the aeration basin concrete structure. The fan is turning on to entrain air from the atmosphere to mix with the wastewater. This will create high air to water exchange surface area and thus leads to more air being dissolved in the water. Fan design is an important factor to consider when designing mechanical aerators. If the fan design is not compatible with the aerator power requirements and the size of treatment basin, it will produces vertical forces on the bearings providing shorter gearbox life and leading to decrease the concentration of dissolved oxygen. The objective of this paper is to investigate the relationship between fan design, vibration level and their effect on the dissolved oxygen level. Vibration measurements were done at three different cases. Firstly, during the old fans with long diameter were installed. Then, after changing the old fans with a new one are different in diameter and design. Finally, after balancing process was done to the new fans. Measurements of dissolved oxygen level were recorded during the three cases. Results indicated that, the vibration level is danger and not permissible on the old fans. Inappropriate design of the old fan diameter increases vibration level about 700%. Vibration level decreases with 76% after changing the long diameter fans with new one. Dissolved oxygen level increased about 4.5 % after balancing process. Vibration level decreases with 79% due to balancing. The results reveal that fan design must be compatible to motor power and size of the treatment basin of the aeration unit.

1. Introduction

Aeration is the process of adding oxygen to water. Maintaining healthy of dissolved oxygen (DO) is one of the most important water quality parameter. Oxygen transfer, the process by which oxygen is transferred from the gaseous to liquid phase, is a vital part of the waste-water treatment process [1]. Due to low solubility of oxygen and consequent low rate of oxygen transfer, sufficient oxygen to meet the requirement of aerobic waste does not enter through normal surface air water interface. To transfer the large quantities of oxygen that are needed, additional interfaces are created by employing aeration process [2]. The mechanical surface aerators are widely used because they offer better efficiency as well as convenience in operation and maintenance. Further, oxygen transfer rate from gas to liquid phase is dependent on various factors for given method of aeration such as dynamic variables like speed, mixing intensity and turbulence, geometrical parameters like size and number of blades, depth of flow etc and physicochemical properties of the liquid.

Mechanical problems associated with aerator drives include noisy operation, abnormal heating, oil leaking, noisy bearings, over heated bearings, and vibration. Of all the mechanical problems that can be encountered, vibration is probably the most misunderstood phenomena. Any amount of vibration is viewed as a sign of impending disaster. Although vibration is not a good sign, it is inherent in any rotating machine. In recent years, there has been a large increase in the use of vibration measuring equipments as a part of a general maintenance program [3]. There are many several causes of vibration in mechanical aerations systems. These causes including mechanical sources such as unbalance, misalignment, ear box, and bearing problems. Also there are hydraulic sources including the excessive immersion level in water, adequate design of fans and basins of mechanical aeration units, and colliding of solid bodies in waste water with the fan during high speeds. These problems leading to dynamic stresses and cause damage, fatigue, wear, and failure [4]. The continuous heavy duty operation life of rotating equipment, such as an aerator, demands a vibration level limiting design that will assure smooth operation long after the unit has been installed. The high maintenance cost of aeration equipment is directly related to the manufactures in ability to control vibration in the aerator systems. High maintenance and equipment failure is a fact of life with many aerators installation [5]. Vibration signature can be taken of piece equipment when it is new and saved for reference. Additional signatures taken over time can give a warning of impending bearing failure or mechanical looseness. The signature analysis will exhibits peaks at a certain frequencies. The frequencies may correspond to shaft rpm, ball passing and gear tooth frequencies and harmonics of these. By denoting at which frequency a vibration increase has occurred, it is possible to pinpoint the problem [6]. Shafts, couplings, gearboxes, and supports are oversized to reduce wear, vibration, and long term maintenance. The slightest vibration in an aerator rotor could cause rapid damage to seals and bearings and detrimentally affect reliability. To ensure optimum new operation, all new and modified product models undergo rigorous testing, and any faults are quickly addressed [7].

2. The problem background

The motivation of this research was initiated by the high vibration level related to operating of aeration units in the tested treatment basin. There are many crakes in the area of aeration basin concrete structure. All crakes are perpendicular to the axes of the structure. This is a sign of relation between crack in concrete and the aerator. Also there was a high splashing due to the high power (200kw) and the relative small size the treatment basin. Also there was a high splashing due to the high power and the relative small size the treatment basin. This treatment basin includes three aeration units each of 3 meter in diameter. As a result of high vibration, the old fans were replaced by a new group with 2.60 meter in diameter and different in design as shown in fig. 1. After 3 months of operation, a problem of unbalance was detected in two fan aeration units. Then balancing process is performed to the out of balance fans.

Research methodology is depending on studying the correlation between the fan diameter, vibration level, dissolved oxygen average, and the performance of aeration unit. The evaluation of the aeration unit performance was through three cases. Firstly, during the old fans with long diameter were installed. Then, after changing the old fans with a new that are different in diameter and design. Finally, after balancing process was carried to the new fans.

Vibration measurements were done to determine the vibration levels. Frequency analysis was done to specify the sources of vibration and exciting frequencies. Balancing was done through out measuring amplitude and phase angle of the aeration unit's fans. Balancing procedures is conducted using Data Collector Type 2526 with the Balancing Option in 7111 / 7112. Dissolved oxygen average was measured before and after balancing process at different depths. Measurements are conducted using three WTW (DO props) at three measurement locations.

Fig. 1 The old and the new fans.

3. Results of dynamic analysis on the old fans

Forced vibration analyses were done on the three aeration units to specify the sources of vibration and define the exciting operational frequencies. All measurements were taken according to the ISO 1-10861 where the root mean square (RMS) velocity were measured for all parameters because it is the most accommodate one for machine diagnosing as it expresses for the energy consumption due to vibration also it takes the time history of vibrations.

The measurement locations are determined on the parts of the aeration units including the motor and gear box at 9 positions representing the axial, vertical, and horizontal directions as shown in fig. 2.

Fig.2 Measurement locations on the aeration units

The measured parameters at every location are overall vibration velocity in a frequency range 10 Hz to 2 kHz and simple spectrum vibration velocity (FFT) in a frequency range from 2 Hz to 1 kHz and. The signals from the accelerometers are directly fed into the 2525 B&K data collector analyzer which possesses an internal signal conditioning system comprising filters, integrators, amplifiers, etc. The signals are then transferred to the PC via USB connection to the 7107 B&K software for signal analysis. The overall vibration level measurements for the three tested aeration unit's fans are shown in table. (1).

The measurements results indicated that there are sever high vibration levels on all tested units. These levels are dangerous and not permissible according to ISO 10816-1 Standard that recommended 2.8 mm/s RMS vibration velocity as an allowable level for such types of machines.

Table (1). Overall vibration level measured on the old fans aeration units.

Measurement locations	directions	Overall vibration level (mm/s)		
		Fan(1)	Fan(2)	Fan(3)
Motor non drive end	axial	2.917	1.226	1.316
	vertical	3.08	4.662	2.831
	horizontal	4.536	3.027	4.545
Motor drive end	axial	1.266	1.39	1.773
	vertical	24.92	28.56	6.256
	horizontal	13.185	6.32	10.924
Gear box upper	axial	6.009	1.041	1.342
	vertical	11.41	7.99	8.63
	horizontal	12.198	5.122	4.842
Gear box lower	axial	1.229	2.246	2.246
	vertical	2.652	1.245	1.245
	horizontal	3.397	2.297	3.449

For aerator (1), the maximum vibration level reached 24.29 mm/s on the motor and 12.198 mm/s on the gear box in radial direction. For aerator (2), the maximum vibration level reached 28.56 mm/s on the motor and 7.02 mm/s on the gear box in radial direction. For aerator (3), the maximum vibration level reached 10.924 mm/s on the motor and 8.63 mm/s on the gear box in radial direction. These results revealed that there is a serious problem occurring with the tested fans. Also, these high vibration levels affected the housing structure and led to high vibration. There are many cracks on the housing structure perpendicular to its axe. This is a sign of the relation between cracks in concrete and the aerator.

Frequency spectrum analysis of the three aeration units indicated that, there are vibration peaks founded at motor running speed (1RPM, 15Hz) in the vertical and horizontal directions. It is obviously noticed that the maximum vibration amplitude reached 9.5 mm/s, 25mm/s, and 7mm/s on aerator (1), aerator (2), and aerator (3) respectively as shown in figs.3, 4, and 5. These high levels of vibration are in the not permissible zone of ISO 10816-1 indicate a great problem for the aeration unit system. It is not safe and dangerous and not allowed to operate at this running condition. The cause of this problem is due to the high power and long diameter of the aerator fan and the relative small size of the basin. Also the bridges are not designed for these fans but for small one.

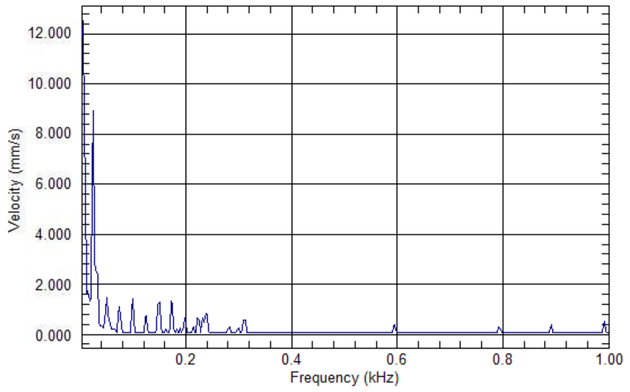

Fig. 3 Frequency spectrum measured on aerator (1).

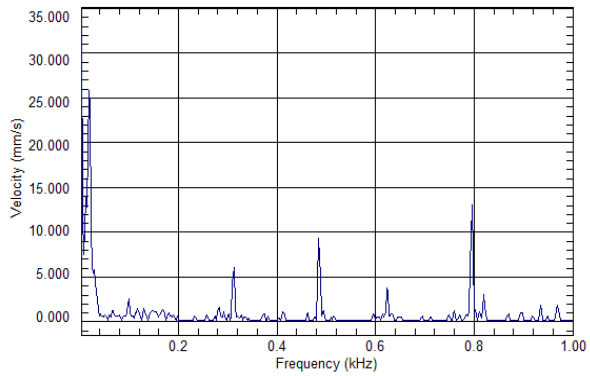

Fig. 4 Frequency spectrum measured on aerator (2).

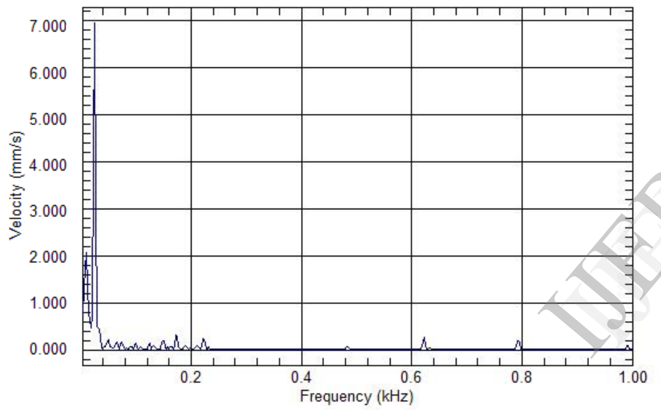

Fig. 5 Frequency spectrum measured on aerator (3).

4. Results of aeration test on the old fans

The deoxygenating-oxygenation procedure used was the non-steady-state reaeration test. According to ASCE, the tested water was deoxygenated with 7.88 mg/L of sodium sulphite and 1500 g of cobalt chloride. After 25 minutes, the measurements of dissolved oxygen concentration are recorded at different depths of the treatment basin bottom. The oxygen readings reached 0.0mg/L, 0.1 mg/L, and 1.24 mg/L. at depths 90, 150, and 240 cm. After maintaining DO between 0.0 and 1.24 mg/L for about 5 minutes, all the aerator were put in operation at the same moment and at the same rotational speed and immersion depth. Increase in DO concentration was measured by DO probe at the different depths. The readings were taken at equal time intervals until DO increased from 0%

saturation to at least 90% saturation. The dissolved oxygen saturation concentration reached 7.9mg/L, 8.1 mg/L, and 8.5 mg/L at depths 90cm, 150cm, and 240cm. Variation of DO with Time for different depths of immersion is shown in fig. 6. it is obvious that the increase in DO concentration is very high in first 20 minutes, and then it gradually attains a saturation value pertaining to the performance of the respective aerators.

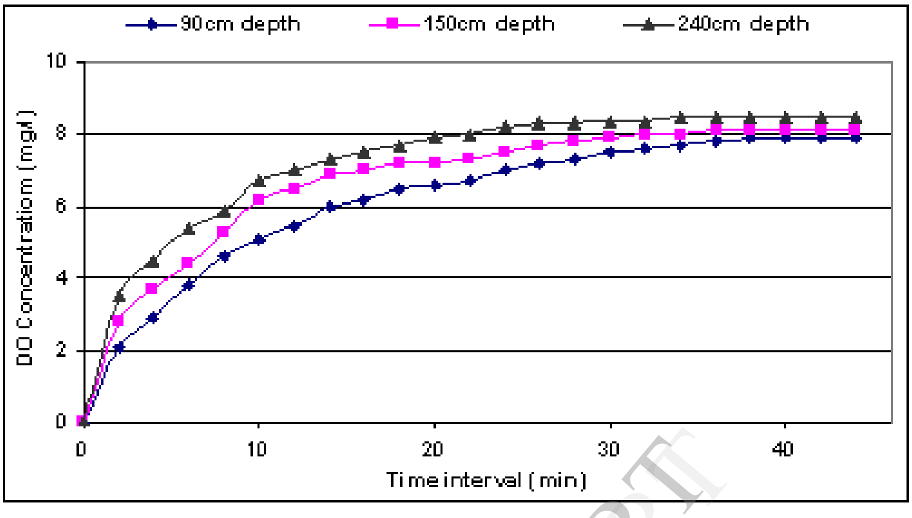

Fig. 6 Variation of DO with Time for different depths

5. Results of dynamic analysis on the new fans

Vibration measurements are repeated after replacement of the old fans with 3m in diameter with a new one smaller one of diameter 2.60m. Table (2) indicates the results of the overall vibration level measured on the three new aeration unit's fans. The results showed that, the measured overall vibration level is obviously decreased on the new fans. For aerator (1), the maximum overall vibration levels reached 11.01 mm/s on the motor and 9.5 mm/s on the gear box in radial direction. For aerator (2), the maximum overall vibration levels reached 8.03 mm/s on the motor and 5.366 mm/s on the gear box in the radial direction. For aerator (3), the maximum overall vibration levels reached 2.6mm/s on the motor and 2mm/s on the gear box in radial direction. Consequently, the overall vibration level decreases about 55%, 72%, and 76% in the radial direction on the three aerators respectively.

Table (2). Overall vibration level measured on the new fans aeration units.

Measurement locations	**directions**	**Overall vibration level (mm/s)**		
		Fan(1)	**Fan(2)**	**Fan(3)**
Motor non drive end	**axial**	**1.863**	**1.32**	**1.226**
	vertical	**2.62**	**2.62**	**2.56**
	horizontal	**2.55**	**2.55**	**1.32**
Motor drive end	**axial**	**1.811**	**1.20**	**1.39**
	vertical	**11.01**	**8.03**	**2.662**
	horizontal	**7.21**	**4.419**	**2.4**
Gear box upper	**axial**	**2.24**	**2.24**	**1.041**
	vertical	**9.3**	**5.366**	**2**
	horizontal	**9.05**	**3.075**	**2.122**
Gear box lower	**axial**	**0.560**	**0.569**	**0.864**
	vertical	**1.87**	**1.87**	**0.502**
	horizontal	**2.06**	**2.06**	**2.297**

The results after replacement indicated that, the overall vibration level of aerator (3) is in the permissible zone of ISO 10816-1. For aerator (1) and aerator (2), the overall vibration level is still high and not permissible.

The frequency spectrum indicates that the exciting frequencies at the running speed (1RPM), which are the source of vibration is obviously decreases. For aerator (1), the maximum vibration amplitude reached 8 mm/s on the motor drive end and 6.5 mm/s on the gear box in the radial direction as shown in figs. 7, 8. For aerator (2), the maximum vibration amplitude reached 5 mm/s on the motor drive end and 3.5 mm/s on the gear box in the radial direction as shown in figs.9, 10. For aerator (3), the maximum vibration amplitude reached 1.3 mm/s on the motor drive end and 400µm/s on the gear box in the radial direction as shown in figs.11, 12. Depending on these results, it is obviously that unbalance problem is the significant main reason of increasing the vibration levels on the aerator fans (1) and (2).

5.1 Balancing procedure

Unbalance is the most common fault associated with rotating shaft. Unbalance vibration is mainly radial. On overhung rotors, axial components may be present as well. High 1X is commonly considered as the unbalance symptom.

The balancing process is performed to the out of balance aeration fans (1) and (2). The balancing procedure is done using Data Collector Type 2526 with the Balancing Option in 7111 / 7112. Balancing is performed using the Influence Coefficient Method. This method is measuring the initial unbalance in two planes according to measuring the amplitude, rotating speed and the phase angle. A trial masses are mounted on the fans to measuring the influence of each trial mass in each plane. Finally, calculating of the resulting correction masses are done then, results are checked with the applied correction masses.

5.2 Results of dynamic analysis after balancing

Forced vibration analyses were done after achieving balancing procedures for the aeration fans (1) and (2). As a result of balancing, the overall vibration level is decreased as shown in table (3).

The maximum overall vibration levels reached 2.419 mm/s on aerator (1) and 2.308 mm/s on aerator (2). Consequently, the overall vibration level decreases about 79% and 71% in the radial direction. The frequency spectrums indicate that the exciting frequencies at the running speed (1RPM) which are the source of vibration is obviously decreases. The amplitudes of vibration peaks reached 1.2 mm/s, 1.75 mm/s on the motor and gear box of aerator (1) as shown in figs. 12 and 13. The amplitudes of vibration peaks reached 1.04 mm/s, 1.3 mm/s on the motor and gear box of aerator (2) as shown in figs. 14 and 15.

Results of aeration test on the new fans

The deoxygenating-oxygenation procedure is repeated as the same pattern on the old fans. The same quantities of sodium sulphite and cobalt chloride are used. The readings were taken at equal time intervals until DO increased from 0% saturation to at least 90% saturation. The measurements of dissolved oxygen concentration are recorded at different depths of the treatment basin bottom. The dissolved oxygen saturation concentration reached 6.4 mg/L, 6.7mg/L, and 7.3 mg/L at depths 90cm, 150cm, and 240cm. As a result of decreasing the fan diameter it is indicated that, the concentration of dissolved oxygen decreased about 18%, 17%, and 14% at different depths.

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After balancing process of fans (1) and (2), the concentration of dissolved oxygen increased again to be 6.6 mg/L, 7mg/L, and 7.6 mg/L at depths 90cm, 150cm, and 240cm. The percentage of increasing reached 3.13%, 4.48%, and 4.11% at different depths. Changing in the dissolved oxygen level during three cases is shown in fig. 17.

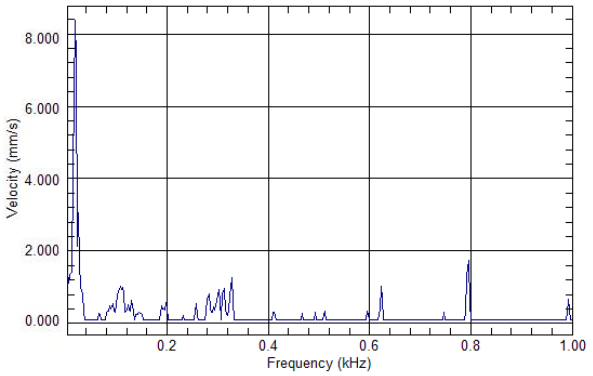

Fig. 7 Frequency spectrum measured on aerator (1) motor.

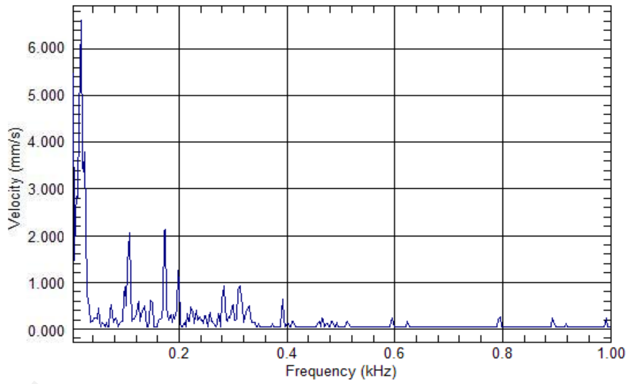

Fig. 8 Frequency spectrum measured on aerator (1) gear box.

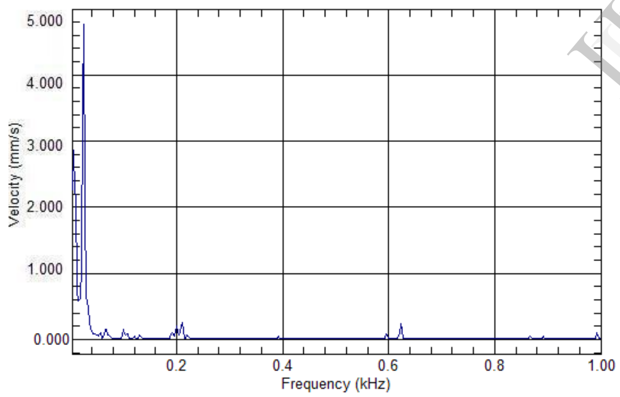

Fig. 9 Frequency spectrum measured on aerator (2) motor.

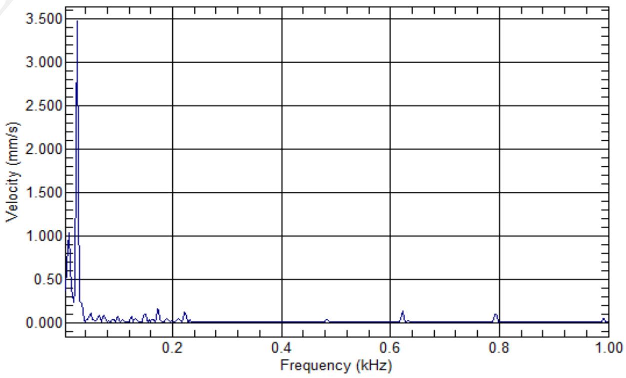

Fig. 10 Frequency spectrum measured on aerator (2) gear box.

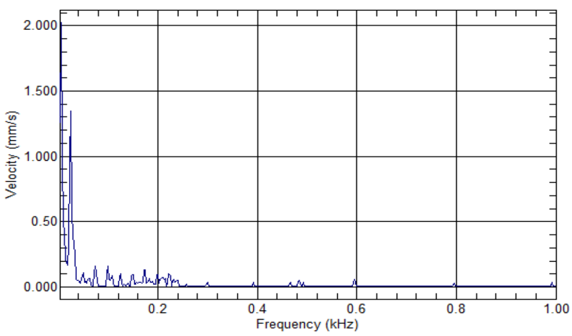

Fig. 11 Frequency spectrum measured on aerator (1) motor.

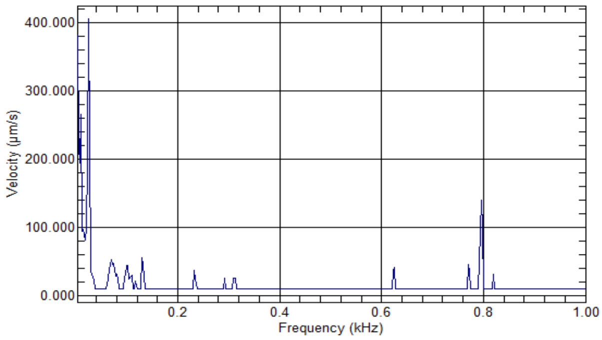

Fig. 12 Frequency spectrum measured on aerator (3) gear box.

Table (3). Overall vibration level measured after balancing.

Measurement locations	directions	Overall vibration level (mm/s)	
		Fan(1)	Fan(2)
Motor non drive end	axial	1.021	1.021
	vertical	1.985	2.12
	horizontal	2.12	1.985
Motor drive end	axial	1.045	1.045
	vertical	2.263	2.308
	horizontal	2.419	1.36
Gear box upper	axial	1.316	0.593
	vertical	2.366	2.63
	horizontal	2.075	2.31
Gear box lower	axial	0.211	0.30
	vertical	0.092	0.092
	horizontal	1.613	1.613

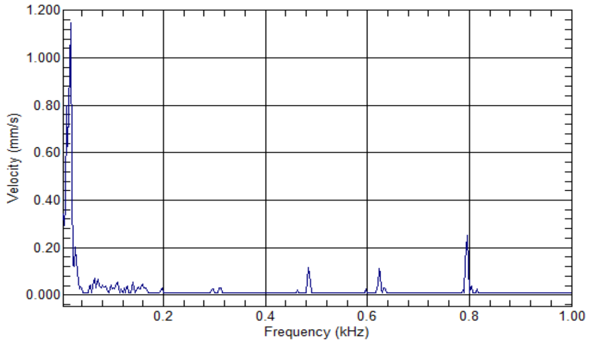

Fig. 13 Frequency spectrum measured on aerator (1) motor.

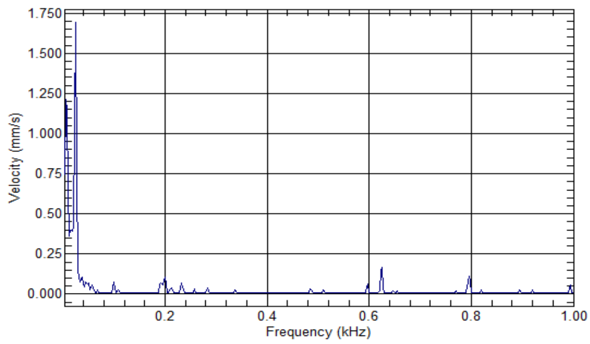

Fig. 14 Frequency spectrum measured on aerator (1) gear box.

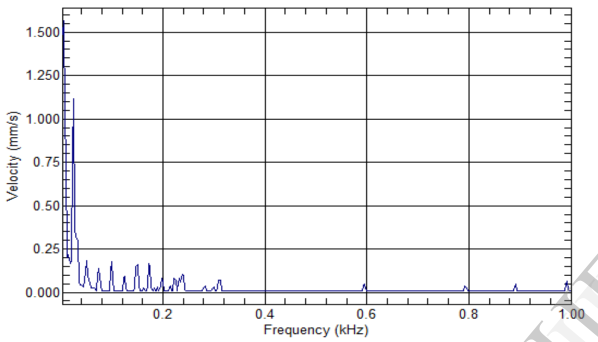

Fig. 15 Frequency spectrum measured on aerator (2) motor.

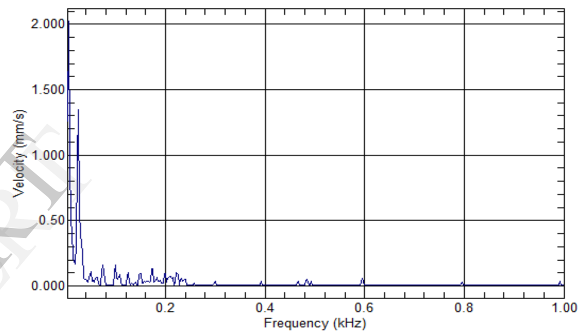

Fig. 16 Frequency spectrum measured on aerator (2) gear box.

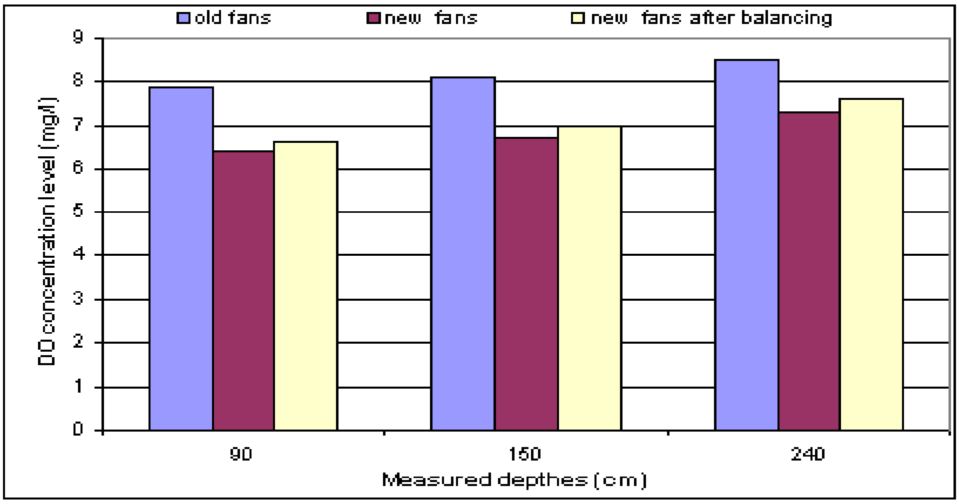

Fig. 17 Variation of measured DO concentration levels during the three cases.

Conclusions

1. Selecting of fan dimensions must be compatible to motor power and size of the basin of the aeration unit.
2. Inappropriate design of fan diameter increases vibration level about 700% on aeration unit (1), 900% on aeration unit (2), and 300% on aeration unit (3) from the permissible zone.
3. High vibration generated from operating the three aeration units affects the housing concrete structure and causes many crakes.
4. Using appropriate fan diameter decreases the overall vibration level about 55%, 72%, and 76% on the three aeration units respectively.
5. Concentration of dissolved oxygen still within range although it decreases about 18%, 17%, and 14% at different depths after installation of small diameter fans.
6. Balancing procedure decreases the overall vibration level about 79% and increasing concentration of dissolved oxygen level about 4.48%.
7. Vibration diagnosis is a very important process to achieve efficient, safe, and reliable operation of aerators.

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