PERFORMANCE EVALUATION OF EL BATTS PUMPING STATION

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ABSTRACT

El Batts Pumping station is located in Fayoum Governorate on the right bank of existing Batts drain about 120 km south of Cairo, at entrance of 0.6 km north-west of Tamiya village. It is equipped with four vertical mixed flow pumping units. The main objectives of this pumping station are to increase the cultivated area by 10000 feddan in the north of Bahr Wahby, improve the irrigation for 20000 feddan in Kom Oshem and El-Gomhorea canal served area, decrease the water level in Karon Lake and improve the drainage conditions in El Batts drain. In this paper, an evaluation of El Batts pumping station is presented. Discharge, pressure, vibration, magnetic field and noise level are measured. Performance of the pumping units, pressure history and noise level during normal operation and power failure are presented. Also, operation guidelines and recommendations for safety are presented. The research indicates minor hydraulic problem for the four pumping units affecting flow rate. Also, the research points out the importance of regular maintenance and replacement to obtain safe and reliable pumping system. El Batts pumping station design and operation have a positive impact on the surrounding area. Its operating system is very effective with good performance if the regular maintenance is prepared.

Keywords: Water management, Pumping Station Performance, Dynamic Analysis and Environmental conditions.

1. INTRODUCTION

El Batts pumping station was designed to pump a maximum of 4.6 (m^3/sec) of drainage water from El Batts drain to the Bahr Wahby canal through a pre-stressed concrete pipeline of 6.8 km, internal diameter of 1800 mm and wall thickness of 142 mm. The static level is 31.32 (m) maximum and 28.88 (m) minimum. The pumping units left considerable amount of drainage water representing more than half of the summer flow**, Wolters and Bas [1].** The station is equipped with four vertical mixed flow pumps, the required capacity of 4.6 (m^3/sec) is achieved by three pumps only while; the fourth unit is as stand-by. The four discharge pipes of pumps are connected to one header. To protect the installations against water hammer, the header is connected to two anti surge vessels, while non-slam check valves are provided for each pump.

The quick opening air valves are distributed along the pipe line while a butterfly valve with 1000 mm diameter is provided for each pump. The surge vessels operate with a constant air cushion above the water level in the tank. The cushion is maintained by two air compressors and associated instrumentation. The two surge vessels deliver additional amount of water to the header in case of power failure. El Batts pumping station has been put into operation since 1993. Due to the importance of this pumping station, which lifts a considerable amount of drainage water representing more than half of the summer flow for re-using it for irrigation, it has been decided to evaluate its hydraulic and dynamic performance to know the state of equipments, maintenance and operation condition in order to prepare recommendations for improving the operation condition.

2. INSTRUMENTATIONS AND TEST FACILITIES

Instrumentations and test facilities are very important to evaluate the performance of any pumping station. Flow measurements, pressure measurements, electric power measurements, magnetic field level, vibration level and noise level are required to give clear measurements to do performance analysis for any pumping station. Special accelerometer, data collector/analyzer model B&K2526 and the machine monitoring software package model B&K7107 were used to measure, collect and analyze vibration level. The best technology to measure the flow-rate through pipeline from its out side without any damage or leakage is the ultrasonic flow-meter. A transit-time ultrasonic flow-meter type (1010) was used to measure the volume flow rate through the pipeline. A calibrated pressure transducer was used to measure pressure at the delivery side of the pumping units. Record card and signal conditioner Type (AT-MIO - 16E - 2) was used to collect the measured pressure value. The time history for pressure measurements were converted to a data file by using an application of LABVIEW software as a data acquisition system. Through another application of the MATLAB software program for signal analysis, the electrical output signals data file was transformed and converted to a pressure head then, plotting of pressure graph was prepared to give a complete view about the pressure history during field measurements at the measuring point. Energy analyzer MICRO VIP MK12 was used to measure voltage, ampere, active power, energy, apparent power, frequency and power factor. Electromagnetic Field Meter type (METRO*LAB* 3-axis THM 7025 3-axis hall Magnetometer) was used to measure magnetic field intensity. The sound level meter type 2236 was used to measure and store noise level history. The results can be transformed to computer through special software provided with the sound level meter to plot the time history for noise level measurements, (equivalent continuous sound pressure level).

3. DYNAMIC PERFORMANCE OF EL BATTS PUMPING STATION

Vibration monitoring is widely recognized as a reliable method of dynamically determining the health of pumping units. Analysis of the overall vibration levels and associated vibration frequency spectra can result into early detection and isolation of common pump problems, **Younes and Helal [2].** Vibration measurement provides sound bases for establishing the running condition of the pumps. There are many causes of vibration in the pumping units including hydraulic, mechanical and structural leading to energy losses, reduction in performance, and decrease of operating life. The vibration data will provide an excellent foundation on which preventive/corrective maintenance programs can be designed, **Nasser [3].** Overall vibration level and dynamic analysis were done on the four units of El Batts Pumping Station as shown in **Figure (1)** using data collector/Analyzer model B&K2526 and the machine monitoring software package model B&K7107. The measured overall vibration levels are summarized in **Table (1).** Vibration was measured on 8 locations as shown in **Figure (2),** on the pump components in the radial and axial direction as follow:

Fig. (1) Photograph of El Batts pumping units

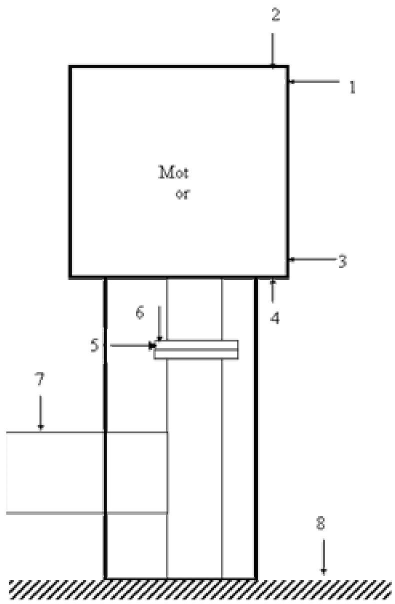

Fig. (2) Location of vibration measured on El Batts pumping unit

Point (1): on the motor non-drive end radial.
Point (2): on the motor non-drive end axial.
Point (3): on the motor drive end radial.
Point (4): on the motor drive end axial.
Point (5): on the pump thrust bearing radial.
Point (6): on the pump thrust bearing axial.
Point (7): on the pump bearing axial.
Point (8): on the pump base (foundation).

Vibration level measured on pump unit No.1 ranges from 0.5 mm/s on the pump to 2.0 mm/s on the motor. According to ISO 10816, vibration level is good and the pump unit is running smooth and safe. The results indicate that pump unit No.1 is dynamically good due to carrying out the regular maintenance and lubrication.

Table (1) Vibration level (mm/s) measured on El Batts Pumping Units

Measurements		Rms Velocity (mm/s)			
		Unit (1)	Unit (2)	Unit (3)	Unit (4)
1	Point 1	2.003	4.377	4.738	14.91
2	Point 2	1.945	3.926	6.476	15.6
3	Point 3	0.818	1.505	2.122	4.335
4	Point 4	1.224	1.514	2.485	8.245
5	Point 5	0.938	1.009	1.595	1.862
6	Point 6	0.527	0.973	1.256	3.171
7	Point 7	0.559	0.589	0.677	0.935
8	Point 8	0.607	0.551	0.468	0.707

Results for pump unit No.2 show that vibration level is 4.37 mm/s on the motor, however, vibration level is in the order of 1.0 mm/s on the pump. Vibration level is good at the pump bearing and allowable at the motor according to ISO 10816. Results for pump unit No.3 show that vibration level is good at the pump (1.0 mm/s), where it is in the just the tolerable zone (beyond allowable zone) at the motor with vibration level equal to 6.47 mm/s. This level indicates that the pump unit is working in the risk zone and maintenance should be carried out soon. On the other hand, vibration level measured on the pump unit No.4 is 15.6 mm/s on the motor non drive end and vibration level is 8.2 mm/s on the motor drive end. This vibration level is in the not permissible zone according to IS010816 and operation at this condition is dangerous. Vibration level indicates that there is/are problems relating to this pump unit and frequency analysis is required to define the source of such high vibration level.

3.1. FREQUENCY ANALYSIS

Before doing the frequency analysis, bearing of the motor and the pump were defined and exciting frequencies of each bearing were determined as shown in **Tables (2), (3), (4) and (5).** Also, blade passing frequency was determined as 62.0 Hz where pump speed is 12.2 Hz and the number of blades is 5. Frequency analysis done on pump unit No.1 at point (1) as shown is **Figure (3)**. Exciting frequencies were 7.3 Hz of level of 0.6 mm/s, 10.9 Hz of level 0.56 mm/s, 12.2 Hz of level 1.7 mm/s, and 43.5 Hz of level 0.27 mm/s. The exciting frequencies did not include any of the bearing frequencies or vane passing frequency concluding that no problem was diagnosed for pump unit No.1.

Table (2) Frequencies of pump thrust bearing (29430)

Bearing designation	22129430E
Pitch diameter (mm)	221
Inner ring defect frequency(Hz)	8.89
Outer ring defect frequency(Hz)	7.11
Rolling element defect frequency(Hz)	5.42
Inner ring rotational speed (Hz)	1.00
Cage rotational speed (Hz)	0.44
Rolling element rotational speed (Hz)	2.71

Table (3) Frequencies of axial pump bearing (23026)

Bearing designation	23026CC
Pitch diameter (mm)	168
Inner ring defect frequency (Hz)	13.79
Outer ring defect frequency (Hz)	11.21
Rolling element defect frequency (Hz)	9.48
Inner ring rotational speed (Hz)	1.00
Cage rotational speed (Hz)	0.45
Rolling element rotational speed (Hz)	4.74

Table (4) Frequencies of the motor bearing (7330B)

Bearing designation	7330B
Pitch diameter (mm)	235
Inner ring defect frequency (Hz)	8.08
Outer ring defect frequency (Hz)	5.92
Rolling element defect frequency (Hz)	4.82
Inner ring rotational speed (Hz)	1.00
Cage rotational speed (Hz)	0.42
Rolling element rotational speed (Hz)	2.41

Table (5) Frequencies of the motor non drive bearing (6234MC)

Bearing designation	623
Pitch diameter (mm)	6
Inner ring defect frequency (Hz)	4.38
Outer ring defect frequency (Hz)	2.62
Rolling element defect frequency (Hz)	3.75
Inner ring rotational speed (Hz)	1.00
Cage rotational speed (Hz)	0.37
Rolling element rotational speed (Hz)	1.87

The maximum vibration level was measured at 12.2 Hz (speed of the pump). Frequency analyses done on pump unit No.2, pump unit No.3, are shown in **Figure (4)** and **Figure (5)**. The results show the same trend as for pump unit No.1. Small vibration levels of magnitude less than 1.0 mm/s was measured in all spectra, however, peak vibration level of magnitude 4.0 mm/s was measured at the running speed of the pump (12.2 Hz). Frequency analysis is done on pump unit No.4 shows different characteristics as shown in **Figure (6)** and **Figure (7)**. Multi exciting frequencies were measured of high vibration level including 4.33 Hz of level 2.56 mm/s, 5.15 Hz of level 8.6 mm/s, 6.5 Hz of level 12.9 mm/s, 6.88 Hz of level 10.3 mm/s, 7.3 Hz of level 5.5 mm/s, 9.7 Hz of level 7.4 mm/s, 10.3 Hz of level 11.9 mm/s, 12.2 Hz of level 5.8 mm/s. The results proved damage of the motor none drive end and motor drive end bearings as the exciting frequencies coincide with frequencies of these bearings. Also, pump bearings were damaged. The cause was misalignment problem of the shaft and couplings and the continuous operation at this condition was the cause of damage happened at the bearings. Lack of maintenance and the need for irrigation water made the problem worse. The pump should not operate at such conditions. The pump failure will happen soon which needs replacement and maintenance that will take much effort, cost, and time. The results outline the importance of regular maintenance and replacement to obtain safe and reliable pumping system. Also, the results indicate minor hydraulic problem for the four pumping units affecting flow rate. Spectra show both mechanical and hydraulic problems however mechanical problems dominate the spectra and negligible exciting frequency at the higher frequency.

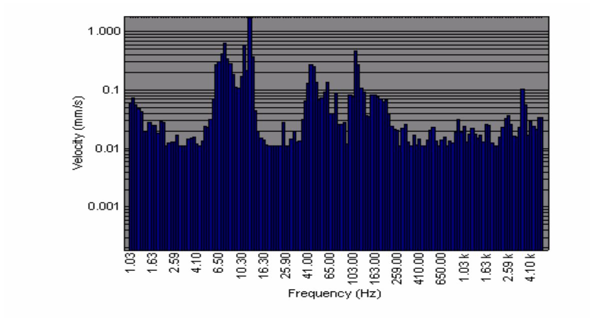

Fig. (3) Vibration spectrum measured on point 1 of pump unit No.1

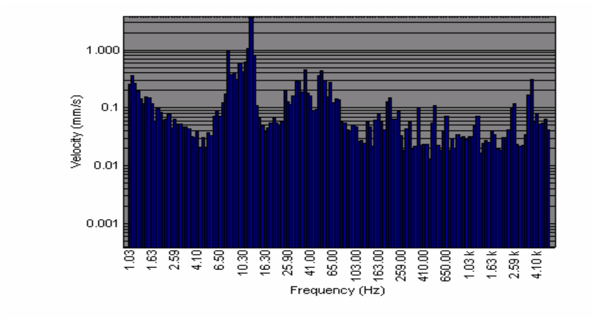

Fig. (4) Vibration spectrum measured on point 1of pump unit No.2

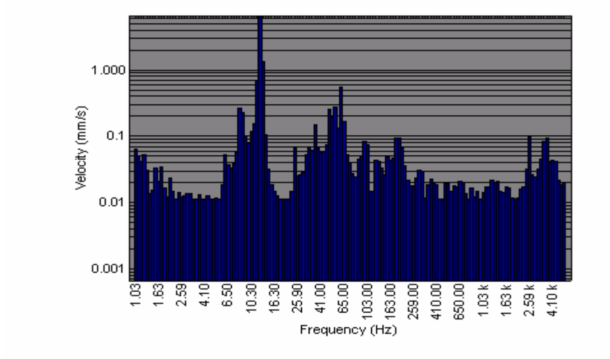

Fig. (5) Vibration spectrum measured on point 2 of pump unit No.3

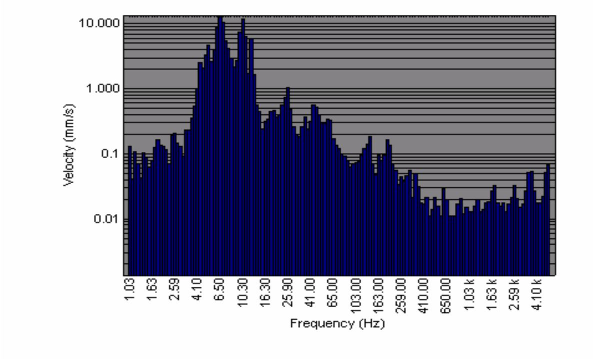

Fig. (6) Vibration spectrum measured on point 1 of pump unit No.4

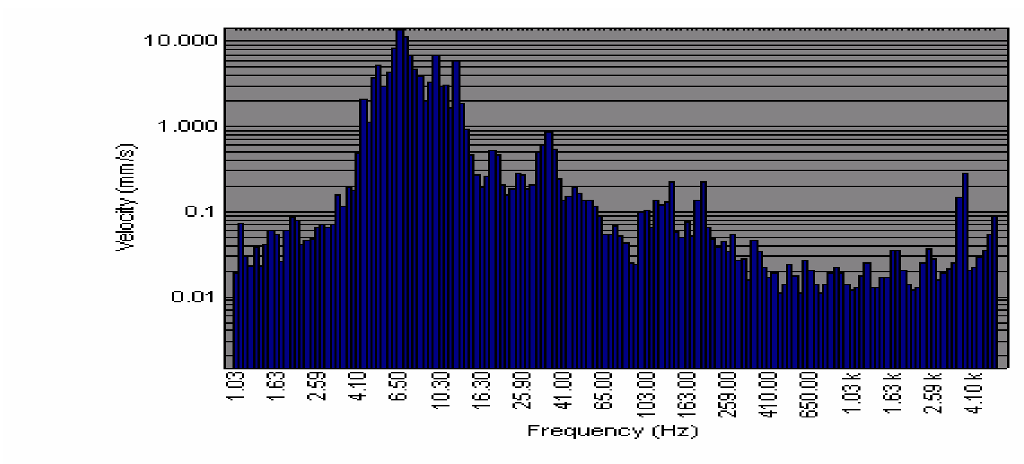

Fig. (7) Vibration spectrum measured on point 2 of pump unit No.4

4. HYDRAULIC PERFORMANCE

Pump performance needs to be monitored to determine when maintenance is required. Actual measurement of flow rate is a simple way to find out how a pumping unit is performing. Measuring flow rate and operating pressures is required to determine if a pumping station is operating efficiently to deliver the desired flow rate. This is a cheap and easy task which should be performed regularly as part of the routine maintenance.

Also, the power required to drive the pump is a direct function of the discharge rate, the total pumping head and the efficiency of the pump at that operating point. The efficiency of the pumping unit during normal operation becomes a significant factor in the capital and operating costs of the pumping unit. To evaluate the performance of El Batts pumping station, delivery pressure, (P_d), discharge, (Q), dynamic water level, (H_s) and electric power, (kW) were measured for three units. The total head and efficiency can be calculated as follows:

$$H_t = H_d + H_s + V^2_d/2g \quad (1)$$

$$W.P. = (\rho * g * Q * H_t)/C \quad (2)$$

$$\eta = (W.P/E.P)*100 \quad (3)$$

where;

C : Constant depending on the head and discharge units
H_t: Pump total head (m)
H_d: Head at the delivery side (m)
H_s: Dynamic water level
V_d: Water velocity at delivery side (m/sec)
W.P: Water power (kW)
Q : Flow rate (m^3/sec)
ρ : Water density (kg/m^3)
g: Acceleration of gravity (m/sec^2)
E.P: Electrical Power Input (KW)
η: Overall Efficiency (%)

Due to a technical problem in the control valves at the delivery side of the pumping units, the performance test was carried out only for one operating point. **Table (6)** shows the test results for unit No.1, Unit No.2 and unit No.4. The total flow rate for the three units is 4.12 m^3/sec. The desired flow rate can be achieved from three units in operation. The rated discharge for El Batts pumping station is 4.6 m^3/sec and the total head is 42 m. Pump performance can be affected by a combination of many factors like sump condition and suction side.

Table (6) Hydraulic test results for three units in operation

Unit No.	Q (m^3/sec)	Total Head (m)	Electric Power (kW)	Water Power (kW)	Efficiency (%)
1	1.25	43.12	876	528.42	60.32
2	1.32	38.9	840	503.39	59.93
4	1.55	33.27	816	505.64	61.97
Total	4.12				

5. WATER HAMMER CONTROL SYSTEM EVALUATION

The pipeline is connected to two anti surge vessels to protect the installations against water hammer, while non-slam check valves are provided for each pump to eliminate reverse flow. The quick opening air valves are distributed along the pipe line while a butterfly valve with 1000 mm diameter is provided for each pump. The surge vessels operate with a constant air cushion above the water level in the tank. The cushion is maintained by two air compressors and associated instrumentation. The vessels deliver additional amount of water to the header in case of power failure. The two vessels are vertical, cylindrical of volume 175 m^3 each (12.25 m high and 4.3 m diameter) as shown in **Figure (8).**

Figure (8) Anti surge vessels at El Batts pumping station

The pressure history was recorded with high response pressure transducer located at pump No.1 outlet. The pressure transducer was provided with an electrical connection, to transfer electrical output signals to data acquisition system. The output signals data file was transformed and converted to a pressure head. Then, the pressure graph was plotted to give a complete view about the pressure history during the recording time. **Figure (9)** shows the pressure history during starting up of pumping unit No.1. It can be seen that, the pressure values increased and decreased gradually. Also, all pressure values are positive (5 m minimum and 42 m maximum). **Figure (10)** shows the pressure history during soft starting of the second pumping unit. The maximum number of operating units in this pumping station is three units. During pumping station shut off, the water hammer control system is provided with soft stopping.

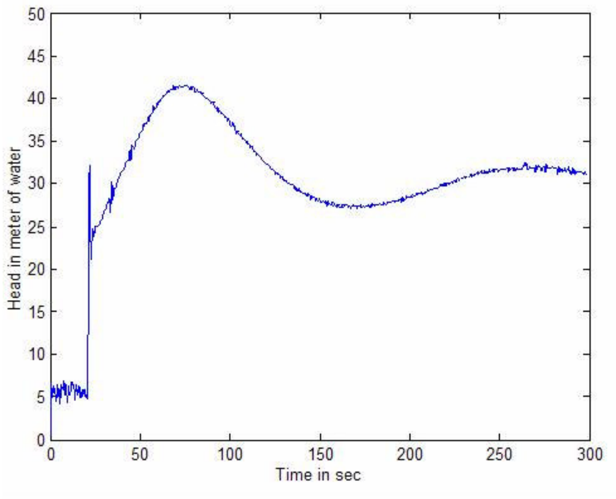

Figure (9) Pressure history during starting up of pumping unit No.1

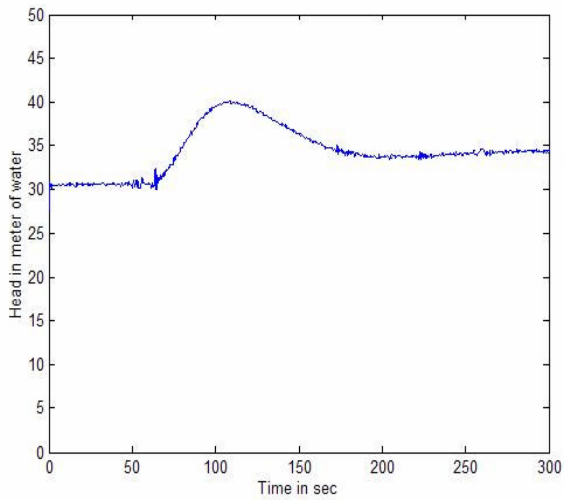

Figure (10) Pressure history during soft starting of the second unit

Figure (11) shows the pressure history for soft stopping for El Batts pumping station. While, **Figure (12)** shows the pressure history during power failure measured at the upstream check valve. It can be seen that, no negative pressure occurred, which means that the water hammer control system is working in a good condition.

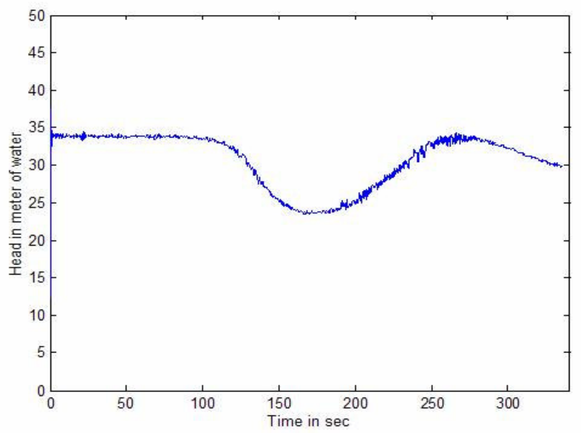

Figure (11) Pressure history during soft stopping

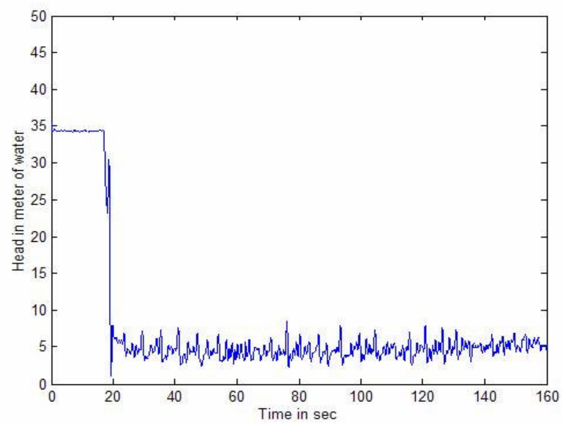

Figure (12) Pressure history during power failure

6. NOISE LEVEL MEASUREMENTS

In any pumping station motors, pumps and auxiliary equipment are the main source of noise. The noise level during operation of pumping station must be evaluated in order to assess the risk of exposure to that level and to determine the maximum exposure time required. **Table (7)** shows the permissible noise exposure time as a standard level. It can be seen that, the increasing of noise level leads to reduce the exposure time, **Egyptian Environmental law [4].**

Table (7) Permissible noise exposure time, [4]

Duration per day, (hours)	Sound level (dB) A
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

When the sound level exceeds the standard level, the personal protective equipment must be provided and used to reduce sound levels to the permissible levels. Noise level measurements are presented to describe the noise level at three-meter distance from the pumping units. The noise level measurements are presented in equivalent continuous sound level. Equivalent continuous sound level is that sound level, which gives the same total energy as that of the varying sound level. It is used for environmental and industrial noise assessment. Noise level was recorded during starting up of the second unit as shown in **Figure (13).** In this case, a sudden change induced impulsive noise reached to 100 dB. While, soft starting was used in starting the second unit as shown in **Figure (14),** it can be seen that the sound pressure level changed gradually. **Figure (15)** shows the noise level during power failure for one unit at El Batts pumping station. Impulsive noise is one of the main impacts of water hammer in pumping stations. Impulsive noise is particularly important both as the cause of annoyance and as a significant hazard to hearing, **Younes and Helal [5].** The maximum value of the noise level reached to 118 dB. In case of power failure for two units, many pluses appeared after reaching the maximum value of noise level as shown in **Figure (16)** until the pressure wave was damped.

7. ELECTROMAGNETIC FIELD MEASUREMENTS

The human feeling to electromagnetic field starts from 400 to 800 Gauss due to the effect of magnetic alternating current. The danger level is above 4000 Gauss and this value is not practical, **Mousa [6].** Electro magnetic field intensity was measured around the pump driving electric motor at different distances by using Electromagnetic field meter type (METRO*LAB* 3-axis THM 7025 3- axis hall Magnetometer). **Figure (17)** shows the electromagnetic field intensity measured at different distances from the electric motor. All measured values are out of dangerous.

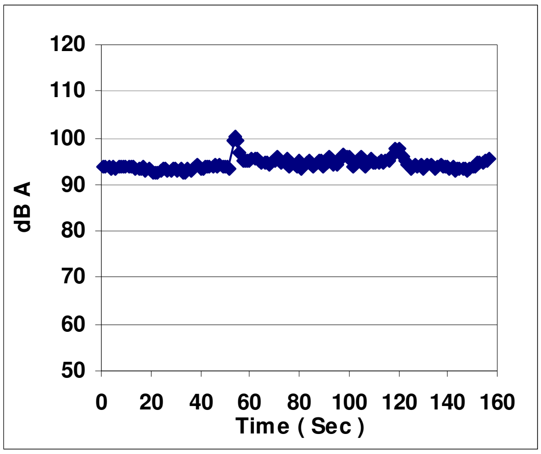

Figure (13) Noise level during starting up of second unit

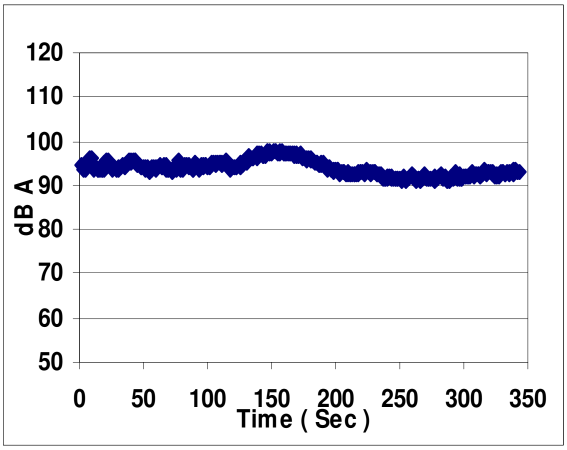

Figure (14) Noise level during soft starting of second unit

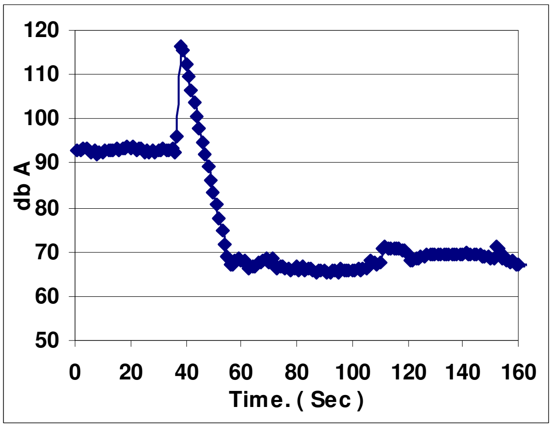

Figure (15) Noise level during power failure for one unit at El-Batts pumping station

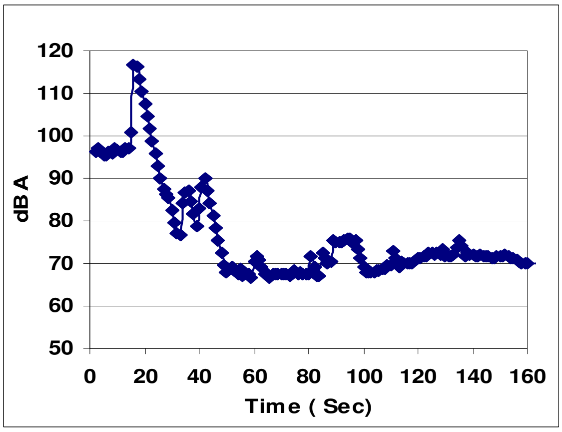

Figure (16) Noise level during power for two units at El-Batts pumping station

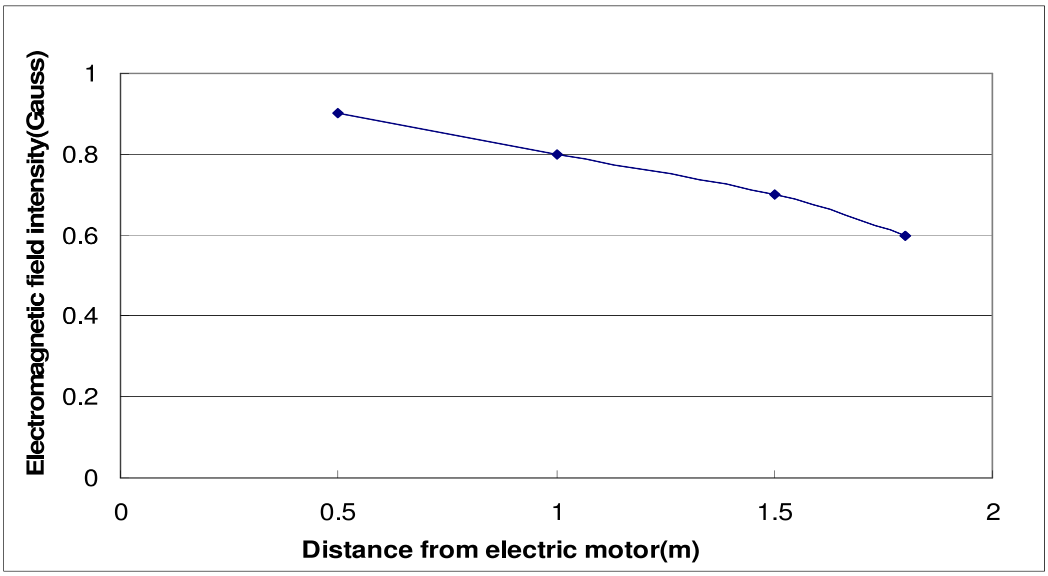

Figure (17) Electromagnetic field intensity at El Batts pumping station

8. CONCLUSIONS AND RECOMMENDATIONS

The research points out the importance of regular maintenance and replacement to obtain safe and reliable pumping system. It can be concluded that, the filed measurements are powerful tool in the field of performance evaluation of pumping stations. The minor hydraulic problems for the pumping units are affecting flow rate. The three pumping units don't fulfill the required discharge and performance curves. Pump performance can be affected by a combination of many factors like sump condition and mechanical problems. The results proved damage of the motor none drive end and motor drive end bearings for unit No.4 as the exciting frequencies coincide with frequencies of these bearings. Also, pump bearings were damaged. The water hammer control system is working in a good condition. Noise level at the pumping station is high due to mechanical problems. All measured values of electromagnetic intensity are out of dangerous. El Batts pumping station design and operation have a positive impact on the surrounding area. Its operating system is very effective with good performance if the regular maintenance is prepared. It is recommended to check pumping unit No.4, the sump and monitor dynamic performance as well as hydraulic performance to obtain efficient, safe and reliable pumping system. The personal protective equipment must be provided and used to reduce sound levels to the permissible levels for safety.

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