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INVESTIGATION OF HYDRAULIC PROBLEMS IN PUMPING STATION; CASE STUDY

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ABSTRACT

Pumping stations play an important role in agriculture development projects. Performance of the pumping stations should satisfy water requirements, and management. There are many problems face these pumping stations affecting their reliability and stability. Hydraulic problems are the most important item in the field of pumping station operation and design. Motivation of this research was presence of wear and pitting impellers and casing of double suction volute casing centrifugal pumps for Ahmed Orabee Pumping Station. Vibration level, hydraulic performance test and visual inspection of impeller wear and pitting show that cavitation problem is the cause of damage. Cavitation normally occurs when liquid at a constant temperature is subjected to vapor pressure either by static or dynamic means. If the local pressure somewhere in the fluid drops to or below vapor pressure and nuclei are present, vapor cavities can be formed. As long as the local pressure stays at vapor pressure and cavity has reached a critical diameter, it will continue to grow rapidly. If the surrounding pressure is above vapor pressure, the bubbles become unstable and collapse. The collapse can be violent and is accompanied by noise, vibration and possible erosion damage to the solid surface.

In this paper a field investigation for hydraulic problems in Ahmed Orabee Pumping Station is presented. The objective of the research is to determine the source of hydraulic problems and to evaluate suction side and operating conditions of the pumping units. Discharge and suction pressures, flow rates, as well as vibration level were recorded simultaneously at different conditions. The data acquisition system is used to monitor cavitation problem as a dynamic signal. The dynamic signal analysis software is used to analyze dynamic signals. The results indicated the importance of continuous monitoring suction pressure, suction intake, and assuring that no more than three pumping units to be operated simultaneously to avoid operating pumps at low efficiency region and obtain high flow rate. Also, the results indicated that, cavitation occurs in the pumping units due to inadequate physical dimension of the suction sump and suction side condition. The current suction sump is not suitable for project development with introducing more pumping units. Double suction volute casing centrifugal pumps are more sensitive to suction and inlet flow conditions than other pumps. The suction conditions according to the original sump design do not fulfill the current operating conditions. The research recommends reviewing and modify suction sump, and suction conditions.

Keywords: Pumping stations, Hydraulic problems, Suction condition and Intake design.

1. INTRODUCTION

Nile River branches and canals are the main water resources for irrigation in Egypt. The land topography is an important factor for water transportation. The water level is very low compared with the irrigated land and consumers. So, with the great demands on limited water supply, water transportation is a very important to fulfill the development and increase water usage efficiency. Ahmed Orabee Intake Pumping Stations located at Ismaliea canal consists of two pumping station (old pumping station and new pumping station), each one has 5 units. The pump type is double suction volute casing centrifugal pump. Pump operating point is 900 m^3/hr discharge and 140 m total head. Two pumping stations lift water through discharge pipeline with 19 km length and 860 mm diameter. After one year of operation of the new pumping station, hydraulic performance decreases where vibration level and noise increase leading to increase dynamic stresses. These dynamic stresses cause wear, fatigue and failure of impeller and casing material. Hydraulic and dynamic tests were performed to assess the performance of pumping units and dynamic problems and to investigate the source of hydraulic problems.

2. EXPERIMENTAL SET UP

A transit-time ultrasonic flow-meter type (1010) was used to measure the volume flow rate. The pressure measurements conducted at the suction and delivery side of the pumping unit. One channel analyzer (B&K model 2526) equipped with high sensitivity accelerometer was used to record vibration behavior during operation at different flow rates and operation conditions. A machine monitoring software package (B&K model 7107) was used to analyze the vibration measured data.

3. HYDRAULIC AND DYNAMIC PERFORMANCE

3.1. Hydraulic Test

Hydraulic performance tests were done during normal operating conditions around the design point, where the control valve in the delivery pipe is used to control flow rate. Discharge, suction pressure, delivery pressure, vibration level were monitored and total head is computed for unit No. 3. **Figure (1**) shows the hydraulic test performance when the pump operates alone. It can be seen that the pump operating point is suitable with the pump characteristic rated values. With the increasing of the control valve opening over rated discharge values, cavitation is produced where performance curve dropped abruptly, decreasing suction pressure and increasing vibration level dramatically. In this case, a transit-time ultrasonic flow-meter fail to measure flow rate value due to aeration in the delivery side. By increasing the number of operating units, the discharge of unite No. 3 decreased and aeration in the delivery side is increased. The results indicated the importance of assuring that no more than three pumping units to be operated simultaneously to avoid operating pumps at low efficiency region and obtain high flow rate **MERI [1].** When poorly developed flow enters the pump impeller, it strikes the vanes and is unable to follow the impeller passage. It means that the flow separation leads to entering air into pumping unit due to hydraulic problems in the suction side.

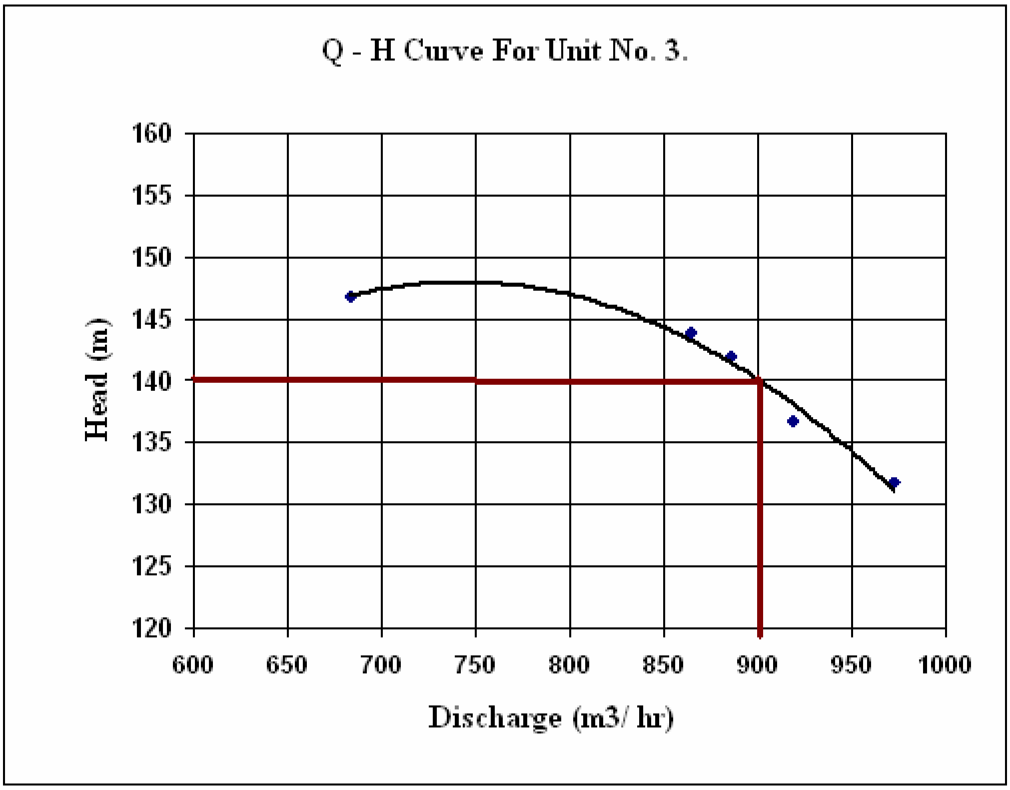


Figure (1). Hydraulic Performance Curve for Unit No. 3

3.2. Vibration Test

There are many causes of vibration in the pumping stations including hydraulic, mechanical and structural leading to reduction in performance, and decrease of operating life **Robertson [2].** Vibration due to mechanical problems can be controlled through more precise balancing of the rotating elements. Flow induced vibration in pumping stations is mainly dependent on operating conditions, inlet distortion, cavitation, surge, etc. Such flow-induced vibration phenomenon is more complex in nature and more difficult to single out than the mechanical causes **Nasser [3],** which are directly related to the operational speed of the pump. 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. Vibration was measured due to operating of a pumping unit No.3 separately and with more individual pumping units to investigate hydraulic problems due to suction conditions. Vibration levels measured with different flow capacity according to ISO 2372 standard as shown in **Figure (2)** with frequency range from 5.15 Hz to 7300 Hz. Vibration level increased dramatically as discharge increased. Operation at nominal design point produces just tolerable level of vibration according to ISO 2372 Standard **Bruel & Kjaer [4].**

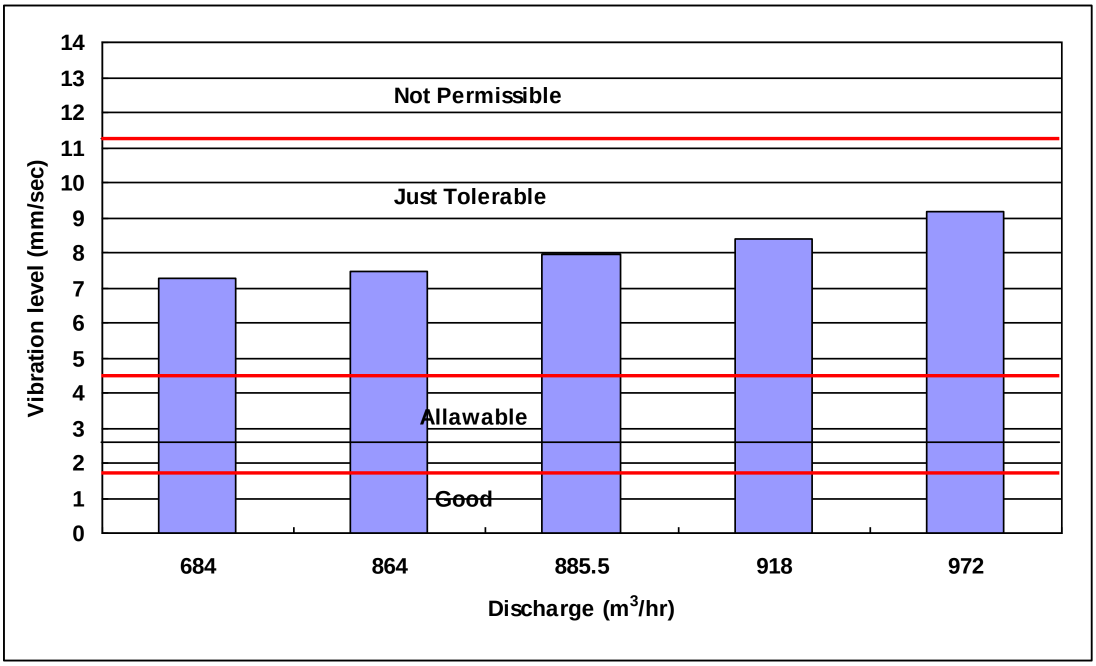


Figure (2) Vibration levels measured within different pump capacity for unit No. 3 (according to ISO 2372 standard)

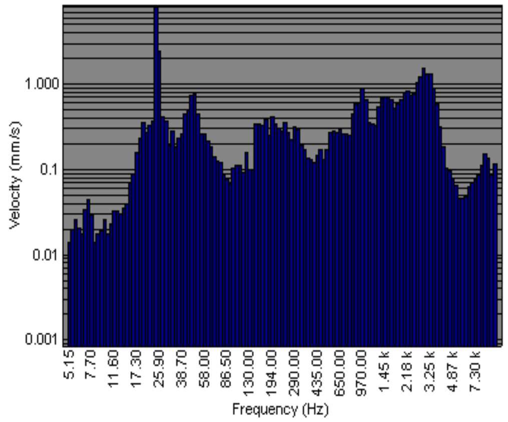
4. DYNAMIC FREQUENCY ANALYSIS

Dynamic performance tests were done during different operating conditions, where the control valve in the delivery pipe is used to control flow. **Figure (3)** shows the vibration Spectrum Measured for Unit No.3 at different operating conditions. **Table (1)** shows the measured data for every case. It can be seen that three units are in operation at the old pumping station in case (A) and (B) with unit No. 3 at new pumping station. The suction pressure is very low and vibration level is very high. Also the ultrasonic flow-meter fails to measure the discharge. In case (C) and (D), there is one unit only from old pumping station works with unit No. 3. By increasing the discharge the vibration level and aeration are increased. Also the ultrasonic flow-meter fails to measure the discharge. In case (E), when unit No. 3 operates alone and the delivery pressure is very high, the ultra sonic flow meter fails to measure the discharge due to low discharge and aeration. By increasing the discharge up the design flow rate as shown in case (F), the vibration level is increased. Also, it can be seen that, the dominant frequencies are pump rotation speed (24.3 Hz), one-third of rotation speed (8.1 Hz), double rotation speed (46.6 Hz), and the vane passing frequency is 146 Hz (6 blades). All these dominant frequencies are from mechanical vibration source except vane passing frequency which is from hydraulic source. The vane passing frequency is observed in all spectra, where amplitude of vibration is high at this frequency due to hydrodynamic forces. These hydrodynamic forces produce random vibration of high amplitudes. Cavitation was detected by monitoring vibration of high non-harmonic frequency nature. Cavitation may also reduce impeller vane pass frequency vibration **Spectra Quest Inc [5].** Double suction volute casing centrifugal pumps are more sensitive to suction and inlet flow conditions than other pumps. The good installation and operation optimize the usage of pumping units. It reduces units failure, power loss, spare parts cost and time of repair. Also, with the pipeline length at the delivery side, (19 km), surge pressure which produces pressure fluctuation due to any change in the flow velocity and vibration are affecting pump performance and stability. With decreasing suction pressure, cavitation is produced where vibration level increased dramatically. Cavitation is one of the most serious problems encountered in the operation of pumps **Snaks [6].**

Table (1) Measured data for Unit No. 3
at different operating conditions

Operating Case	Discharge (Litter/Sec)	Suction Pressure (bar)	Delivery Pressure (bar)	Vibration Level (mm/s)	Condition
A	Fail	- 0.47	13.5	8.848	With 3 more Units
B	Fail	- 0.48	13	9.106	With 3 more Units
C	184	- 0.43	13.8	7.5	With one more unit
D	Fail	- 0.44	13	8.001	With one more unit
E	Fail	- 0.36	15.2	7.735	Alone
F	270	- 0.42	12.5	9.179	Alone

Cavitation, not only causes a loss of performance in the operation, but also damage to impeller and casing as shown in **Figure (4).** Impeller is the most important part in the pumping unit. Impeller Damage may be caused by the up normal operation conditions. It receives the output of the prime mover and transmits energy as pressure and velocity to water of the specified flow rate which passes through the impeller. So, impeller design has a serious influence on the pump performance. Impeller check must be conducted to determine the operation conditions effect on the impeller. The impeller treatment by using special recommended material should be conducted. In some cases, it should be replaced and renovated.



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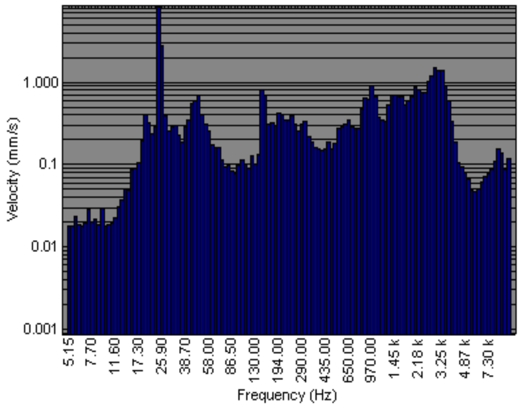

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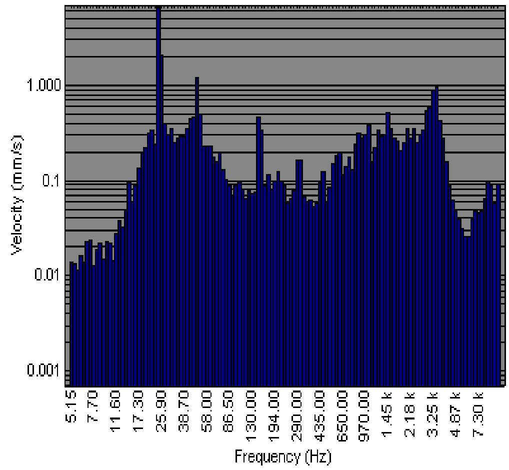

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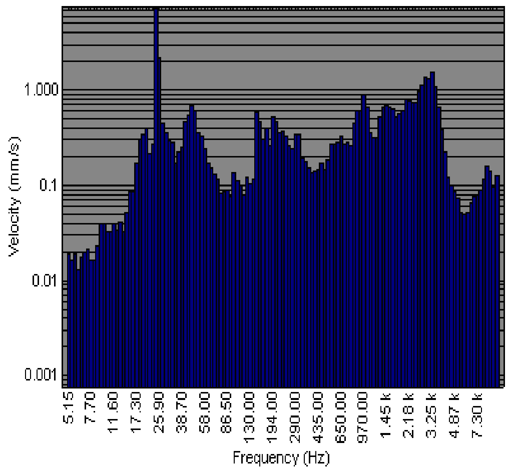

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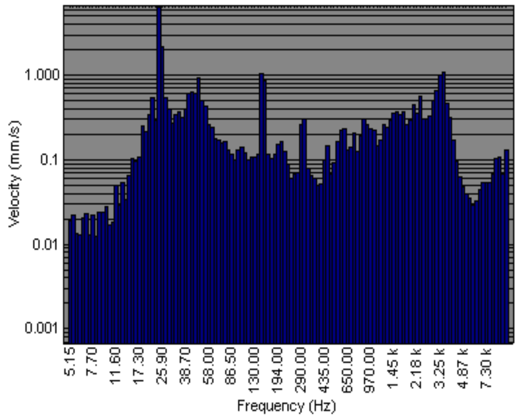

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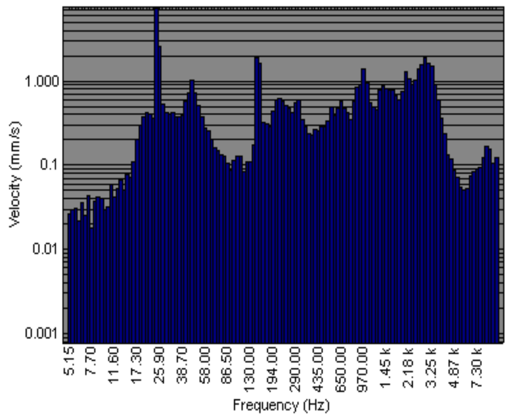

F

Figure (3). Vibration Spectrum Measured for Unit No. 3 at different operating conditions

Figure (4). Cavitation damage at the casing and pump impeller

5. INSPECTION OF SUCTION CONDITION

Many hydraulic problems can be generated from suction conditions. **Figure (5)** shows the suction pipe, Contour type reducer and suction elbow. Suction pipe has many bends and the length is too long. It leads to increase priming time. Foot valve should be provided when the suction lift is not very high to facilitate priming. End suction side should have a straight runs of 5 to 10 times of pipe diameters minimum. When a straight run of pipe at pump suction cannot be provided, certain arrangements of fittings must be avoided. For a double suction pump, an elbow whose plane is parallel to the pump shaft as shown in **Figure (5)** should not be used.

Figure (5) Suction pipe, pipe reducer and elbow at pump suction

Reducers are installed just ahead of the pump suction when the pipe is larger than the pump nozzle. Contour type reducer as shown in **Figure (5)** is not recommended. Suction reducer should be installed to avoid creation of air pockets. Reducers used at the pump suction should be of the conical type as shown in **Figure (6).**

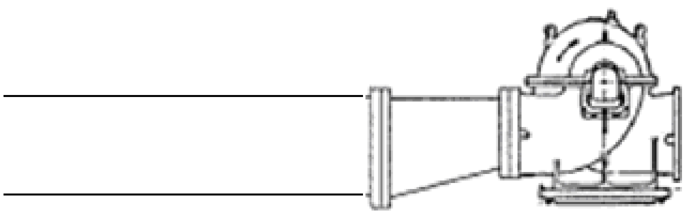

Figure (6) Recommended suction pipe and reducer at the suction side

Suction pipe velocity should not exceed the velocity in the pump suction nozzle. Pipe velocity may need to be reduced further to satisfy pump net positive suction head requirements and to control suction pipe losses. With pipe velocity in the 1.5 to 3 m/sec range, and with suction piping containing valves, fittings and bends, a straight pipe length of 5 to 10 diameters may be required to insure uniform flow to pump suction. Straightening vanes or tubes may serve the same purpose. This pump design feature is very susceptible to non-uniform inlet flow because when liquid velocity varies and does not meet the pump design assumption of a uniform velocity striking the impeller eye, flow separation results which causes cavitation and associated problems. It is common to use an elbow close-coupled to the pump suction which creates a poorly developed flow pattern at the pump suction. Since pumps require well-developed inlet flow to meet their potential, a pump may not perform or be as reliable as expected due to a faulty suction piping layout such as a close-coupled elbow on the inlet flange. When poorly developed flow enters the pump impeller, it strikes the vanes and is unable to follow the impeller passage. The liquid then separates from the vanes causing mechanical problems due to cavitation and vibration, and performance problems due to turbulence and poor filling of the impeller. This results in premature seal, bearing and impeller failure, high maintenance costs, high power consumption, and less-than-specified head and/or flow. With a double-suction pump tied to a close-coupled elbow, flow distribution to the impeller is poor and causes reliability and performance shortfalls. The elbow divides the flow unevenly with more channeled to the outside of the elbow. Consequently, one side of the double suction impeller receives more flow at a higher velocity and pressure while the starved side receives a highly turbulent and potentially damaging flow. This degrades overall pump performance (delivered head, flow and power consumption) and causes axial imbalance which shortens seal, bearing and impeller life. By imparting a swirl to the flow entering the elbow, the flex cutaway rotation-vane enables the liquid to negotiate the turn and be evenly distributed to each side of the impeller **(Metraflex [7]).** With the flex cutaway rotation-vane, flow and head characteristics will approach factory rated pump test performance, cavitation and noise will diminish, and seal, bearing, and impeller life will improve. The flex cutaway rotation-vane compensates for specification and installation constraints and attacks the root-cause of poor pumps performance due to faulty suction piping layout. With flex cutaway rotation-vane installation, pump performance and reliability will be maintained despite close-couple elbows on pump suctions, even when applied in high suction specific speed, and double suction pumps.

6. INSPECTION OF INTAKE AND SUMP

The optimum design for intake will bring relatively clear water directly into the pump suction area at a low velocity. The function of the intake structure is to supply an evenly distributed flow to the pump suction. The current suction sump consists of two reservoirs one for each pumping station. The first one is connected with Ismailia canal and new pumping station through pipeline 1000 mm pipe diameter. The second one is connected with first reservoir and old pumping station through two pipes with 800 mm diameter for each. The flow velocity through pumping station intake depends on the number of operating units. The flow velocity in this case is too high due to inadequate physical dimension of the intake, suction sump and suction side condition. For the installation of pumps in sumps, a lot of standard solutions must be provided like, minimum water level, sump dimension, the distance between units and wall and units arrangement. Minimum water level should be adequate to satisfy the particular pump design. Water level in the pumping station intake should be monitored permanently to avoid operation at low water level which introduces hydraulic problems **(Rajendran et al. [8]).** When the water level in the sump fails below some critical value, Different types of vortices are observed in a water-pump intake sump so the flow is complex to simulate **(Younes et al. [9]).** Vortices originate from the free surface can become strong enough to draw air and floating debris into pump, resulting in vibration and cavitation. Entrained air can cause noise, vibration, fluctuations of load and consequent physical damage. Average velocity should be kept low, about 0.6 m/s maximum for flow into the pumping station and 0.3 m/s maximum for the approach flow if there are no solids in the water **(Hydraulic Institute [10]).** Cavitation occurs in the pumping units due to inadequate physical dimension of the intake, suction sump and suction side condition. The current suction sump can not contain project development with introducing more pumping units due to high velocity at the intake and non uniform flow.

7. CONCLUSIONS AND RECOMMENDATIONS

The research indicated the importance of continuous monitoring suction pressure, suction intake, and assuring that no more than three pumping units to be operated simultaneously to avoid operating pumps at low efficiency region and obtain high flow rate. Also, the results indicated that, cavitation occurs in the pumping units due to inadequate physical dimension of the suction sump and suction side condition. The current suction sump can not contain project development with introducing more pumping units. Double suction volute casing centrifugal pumps are more sensitive to suction and inlet flow conditions than other pumps. The suction conditions according to the original sump design do not fulfill the current operating conditions. The research also, points out and suggests that, codes and recommendations must be conducted in the design and installation stage to eliminate hydraulic problems. Water level in the pumping station intake should be monitored permanently to avoid operation at low water level which introduces cavitation problem. Decrease the water level will induce vortices swirl flow at the pump inlet resulting to severe vibration at non-harmonic high frequencies. Pump operation close to operating point as possible leads to safe operation and avoid flow problems such as recirculation and surge which produce pressure fluctuation and vibration affecting pump performance and stability. The results indicated that, the importance of installing another pipeline to satisfy the number of operating units. The research recommends reviewing and modify intake, suction sump and suction conditions.

REFERENCES

[1] Mechanical & Electrical Research Institute (MERI), "Hydraulic and dynamic Evaluation of Ahmad Oraabee Pumping Stations" Technical Report, Delta Barrage, Egypt, 2004.

[2] Robertson., J. S., "Drainage and Irrigation Pumps", Chapter 10.3, Pump Handbook (Ed. Karassik, I.J., Krutzsch, W.C., Fraser, W.H. and Messina, J.P.), pp. 10.39-10.49, McGraw-Hill, New York, 1976.

[3] Nasser, M. A., Mechanical Vibrations Problems and Solutions in Large Scale Pumping Stations, Engineering Research Journal, Vol. 50, University of Helwan, Faculty of Eng. Tech., Mataria, Cairo, Nov., 1996.

[4] Bruel & Kjaer (B&K), "Machine Condition Monitoring," BR 0267-13, Denmark, 1989.

[5] Spectra Quest Inc., "Air Bubble and Cavitation Vibration Signatures of a Centrifugal Pump" 8205 Hermitage Road Richmond, VA 23228 (804)261-3300 www.spectraquest.com , May, 2006.

[6] Snaks, R., et al., "Pumping Station Design", 2nd edition, Butterworth-Heinemann, Boston, USA, 1998.

[7] Metraflex Company, "CRV Flex and Pump Applications", Technical Report, 2323 Hubbard St., Chicago, IL 60612, www.metraflex.com

[8] Rajendran V. P., Constantinescu G.S. and Patel V.C., "Experiments on flow in a model water-pump intake sump to validate a numerical model" Proceedings of EDSM, ASME Fluids Engineering Division Summer Meeting, Washington, DC. June 21-25, 1998.

[9] Younes M. A, Abdel-Rahman S. A., and Helal M. A., "Dynamic Response and Instability of Propeller Pumps", Proceedings of the International Conference, "IMAC –XX", Organized by the Society for Experimental Mechanics, Orlando, Florida, s28p04, Feb. 2003.

[10] Hydraulic Institute, "American National standard for centrifugal pumps for nomenclature, Definitions, application and operation", pp. 90-98, ANSI/HI 1.1-1.5, 1994.