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Detecting Cavitation in a Vertical Sea water Centrifugal Lift Pump Related to Iran Oil Industry Cooling Water Circulation System

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Abstract**—**Cavitation is one of the most well-known process faults that may occur in different industrial equipment especially centrifugal pumps. Cavitation also may happen in water pumps and turbines. Sometimes cavitation has been severe enough to wear holes in the impeller and damage the vanes to such a degree that the impeller becomes very ineffective. More commonly, the pump efficiency will decrease significantly during cavitation and continue to decrease as damage to the impeller increases. Typically, when cavitation occurs, an audible sound similar to 'marbles' or 'crackling' is reported to be emitted from the pump. In this paper, the most effective monitoring items and techniques in detecting cavitation discussed in details. Besides, some successful solutions for solving this problem for sea water vertical Centrifugal lift Pump discussed through a case history related to Iran oil industry. Furthermore, balance line modification, strainer choking and random resonance in sea water pumps discussed. In addition, a new Method for diagnosing mechanical conditions of sea water vertical Centrifugal lift Pumps introduced. This method involves disaggregating bus current by device into disaggregated currents having correspondences with operating currents in response to measured bus current. Moreover, some new patents and innovations in mechanical sea water pumping and cooling systems discussed in this paper.

Keywords**—**Cavitation, Vibration Analysis, Centrifugal Pump, Vertical Pump, Sea Water Pump, Balance Line, Strainer, Time Wave Form (TWF), Fast Fourier Transform (FFT)

I. Introduction

THE vapor bubbles that form in a pot of boiling water will eventually rise to the surface and burst. The energy release (explosion) that occurs upon burst is quite small. However, when that same bubble forms in the vanes of an impeller and begins its outward migration, an extremely powerful force can be released [1].

In addition, cavitation has a great influence on mechanical properties of different industrial materials like the fracture toughness [2].

Cavitation (from cavity) is defined as the rapid formation and collapse of vapor bubbles or pockets in a liquid, due to dynamic action, and resulting in the formation of cavities on the surfaces of solid boundaries. These solid boundaries can exist in any number of structures including hydrofoils, pipes, and fittings but, in our industry, the primary victims are impellers and propellers. Cavitation was first explained in 1917 by the English physicist, Lord Rayleigh, as he was studying mysterious metal erosion on ship propellers. Cavitation, itself remains a largely misunderstood phenomenon although its effects upon the surfaces of an impeller have been witnessed by many of us in the pump industry. Actually, this is not too surprising when one considers the complex physical behavior of the relatively, simple water molecule and the dynamic encounters within the centrifugal pump. Cavitation may occur in different type of machine like centrifugal pumps, water turbine as well as ships and submarines main impellers. National standards represent a broader range of required operational characteristics, in particular for tests with simulation conditions and evaluation of the cavitation corrosion [3].

Cavitation is a common occurrence but is the least understood of all pumping problems. Your pump have cavitation if knocking noises and vibrations can be heard when it is operating. Other signs may be erratic power consumption and fluctuations or reductions in pump output [4].

Sub critical flow is considered a safe flow because the flow velocity is low in this case and the less is the flow velocity the less would be the cavitation risk [5].

If you continue to operate your pump when it has cavitation, it will be damaged. Impeller surfaces and pump bowls will pit and wear, eventually leading to mechanical destruction. In addition, recent investigations indicated that intense pressure fluctuation might cause harmful amount of cavitation in industrial equipment [6].

Cavitation in sea water vertical Centrifugal lift Pumps discussed in details in this paper. As everybody know big industrial plants usually installed near sea or big rivers. These kinds of industrial zones are thirsty of cooling water of the sea or big rivers. Because of the large amount of industrial equipment, these kind of vertical centrifugal pumps usually are huge or high KW pumps and considering as most critical equipment for their industrial plants. Such equipment lift sea water to another stages connected to plants. The water is circulated in cooling tower fans and related pumps to increasing efficiency of cooling system. The number of the huge sea water pumps usually vary from 3 to 12 depends to the size of the industrial plant.

Nowadays several modeling techniques developed to estimation of failure probability like cavitation in different type of industrial equipment. This kind of information will help us to avoid condition that causes such costly maintenance action in big industrial plants. Such data and information

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could help us in modern maintenance management systems like reliability-centered maintenance (RCM) [7].

Cavitation also has some serious harmful effects on other industrial fields like agricultural, food and wine industries. During cavitation, micro bubbles form at various nucleation sites in the fluid and grow during the rarefaction phase of the sound wave. Then, in the compression phase, the bubbles implode and collapsing bubbles release a violent shock wave that propagates through the medium [8].

Sea water pump in big industrial plants are usually huge equipment typical sea water vertical Centrifugal lift Pumps shown in Fig. 1 [9].

Fig. 1 Typical sea water vertical Centrifugal lift Pumps

Cavitation usually shows itself in blade pass frequency in FFT also cavitation is caused by the collapse of small bubbles that occurs during local boiling at certain condition of the fluid like low dynamic pressure. The collapses are short in time and thus wide in frequency. The resonances are exited throughout the spectrum especially high frequencies are exited also in envelope spectra and increasing of the background level with no distinct lines is seen. The sea water vertical Centrifugal lift Pumps usually equipped with bush bearings therefore vibration usually cannot shows itself on velocity and acceleration.

However, displacement peak to peak found more effective in such equipment. Typical strong huge displacement is the most usual vibration behavior of these kinds of machines. That is because of random resonance in such huge equipment. On line vibration, monitoring systems also developed in recent years for sea water pumps.

Furthermore, Technical devices that could be effective in detecting cavitation are data collectors like Vibro 60 and Easy Viber. They are equipped with related soft wares XMS and Spectra pro respectively [10], [11].

NPSHR experimental curve for pumps could be effective in detecting cavitation. An example of NPSHR experimental curve for centrifugal vertical water pumps represented in Fig. 2 [12].

Besides, Fig. 3 representing the effects of cavitation in seawater centrifugal lift pump.

In addition, the methods of measuring, monitoring and analyzing vibrations in rotary equipment explained in [13].

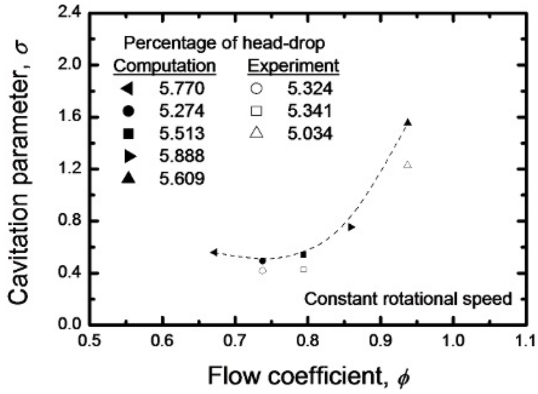

Fig. 2 Cavitation parameter via flow coefficient/percentage of head drop (computation-experiment)

Fig. 3 The effects of cavitation in a sea water centrifugal lift pump impeller

II. Experimental Details

A. Basic Principals

Cavitation could be detected by condition monitoring techniques like time wave form (TWF) or fast Fourier transform (FFT) analysis [14].

This paper discussed cavitation vibration analysis in details. All vibration analysis websites and documents discussed cavitation from different aspects like monitoring, machinery and process. This paper organized base on all of my work experiences and observations in petrochemical companies.

Cavitation was one of the first malfunctions investigated in the Pump Laboratory. It occurs when the Net Positive Suction Head Available (NPSHA) drops below the Net Positive Suction Head Required (NPSHR) for a centrifugal pump. The pump manufacturer typically provides the NPSHR experimental curve. Flow velocity and cavitation index are two important factors influencing cavitation damage. Based on these factors, five different damage levels from no cavitation damage to major cavitation damage have been determined [15].

Cavitation will occur when the net pressure in the fluid is less than the vapor pressure of the fluid. This malfunction can be extremely destructive to a centrifugal pump. Cavitation can cause pitting of the impeller, impeller vanes, and pump casing.

In some instances, cavitation has been severe enough to wear holes in the impeller and damage the vanes to such a degree that the impeller becomes very ineffective. More commonly, the pump efficiency will decrease significantly during cavitation and continue to decrease as damage to the impeller increases. The ultrasound waves on a liquid produce cavitation, which grow in size before violent collapse in microseconds. The violent collapse produces very powerful hydro mechanical shear forces in the bulk liquid surrounding the bubble [16].

The collapse of vapor cavities is also the origin of erosions that accompany cavitation. When a bubble shrinks, its shape is indeed unstable; there is a sort of micro-jet, which, approximately a solid wall tends to move towards it. Velocity in the jet is high (almost 100 m / s), it produces a micro crater when it hits the casing walls. When a solid surface and is the seat of repeated collapse, it starts to look orange peel and after stripping material, an aspect of sponge, before being pierced from side to side. In addition, the resistance of a material to cavitation erosion is naturally linked to the other mechanical characteristics of the material like resilience, and hardness in particular [17].

Cavitation risk calculation is one the most important factors in preventive maintenance. There are some specific formulation identifies in different types of industrial equipment technical documents. Most of them based on operation and machinery considerations. Nowadays several modeling approaches are investigated for different types of industrial equipment especially centrifugal pumps [18].

Monitoring the dynamic inlet pressure may be a better indicator of cavitation than monitoring the static pressure at the inlet and dynamic pressure is a direct indication of cavitation, whereas NPSHA monitoring is an indirect indicator. In this paper cavitation discussed in details for sea water vertical Centrifugal lift Pumps in vibration aspects [19].

In addition, there are several process parameter optimizations in design process of sea water pump manufacturing that should be carefully identified to reduce cavitation. Materials used in sea water pumps depend upon many factors that include sea water quality, materials limitations and processing characteristics, materials cost and availability. Many newer high alloy stainless steels not widely used a few decades ago have now become standard alloy offerings for sea water pumps [20].

Schematic diagram of all sea water vertical Centrifugal lift Pumps represented in Fig. 4. Trash rack could replace with different types of industrial strainers.

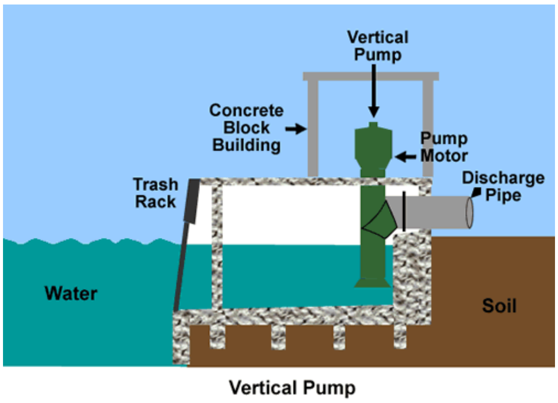

Fig. 4 Schematic diagram of sea water vertical Centrifugal lift Pumps

B. Observation and Technical Consideration

One of the challenging vibration characteristic of vertical sea water pumps is sudden huge movement of electromotor with its vertically huge connected cables and facilities. Sometimes these kind of huge movements are visible and larger than 10cm or even more. These kinds of movements are not dangerous because of the huge dimension of the equipment and consider as some normal random moves in their vibration and operation behaviors. New investigation for sea water vertical Centrifugal lift Pumps by mechanical shaker test performed in an industrial plant. Shaker tests were conducted on pump to measure the mechanical natural frequencies of these kinds of pump and motor systems. The results cause to reduce vibration levels of the pumps and motors by designing diagonal structural braces were installed to the top of the pump [21].

Besides, recirculation was identified by several items like sudden increase in nonsynchronous vibration of the pump, motor and piping as the discharge pressure was increased and flow reduce also sudden backflow observed from underwater videos of the pump inlet detects by sea water main process board on line cameras. Traditional condition monitoring system of sea water pumps based on manual data collected from electromotor in two points and the first bush bearing of the pump. Such information was not sufficient for a good, complete and effective monitoring system. Nowadays sea water vertical Centrifugal lift Pumps equipped with additional transducers for all stages or minimum last stages to increase on line vibration monitoring efficiency. Method for diagnosing mechanical conditions of rotating machines like sea water vertical pumps involves disaggregating bus current by device into disaggregated currents having correspondences with operating currents in response to measured bus current developed in recent years. The device, which is preferably embedded in a power distribution enclosure, enables analysis of conditions of electromechanical machines and alternatively also their driven or driver devices.

The analysis uses operating voltages and currents supplied to or from the electromechanical machines. Since these voltages and currents are available at the enclosure, wiring or any other communication means to any sensors on the electromechanical machines or on the driver or driven devices are not necessary. The embedded device may optionally transmit its results to a computing or monitoring device remote from the enclosure, preferably wirelessly. The embedded device may receive all its power from an existing, conventional potential transformer in the enclosure, so that the embedded device may be retrofitted to the enclosure without the addition of any wiring external to the enclosure [22].

Sea wave action powered pump that has coupled lever arm struts connected to floats on tubular pumping elements is one of the new patents in mechanical sea water pumping systems. Method and apparatus were in complex multi planar surface motion of the sea or other fluid body is converted into usable energy. One embodiment of the apparatus comprises a pair of flexible tubular pumping elements that pump a fluid, such as sea water, to load such as a storage means or an energy converter such as a turbine driven prime mover. The apparatus makes use of multi planar waves and surface currents that axially flex the pumping elements to provide hydraulic or pneumatic pressure for pumping the water [23].

Centrifugal pump, particularly radial pump or semi-axial pump or sea water pump for supplying sea water, comprises housing with feed area and drying area, where drive shaft is provided, which is rotating opposite to housing is also recently developed in Germany. In a centrifugal pump, in particular a radial or semi-axial pump including a housing with a pump chamber and a dry chamber, a drive shaft rotatable supported in the housing and connected to an impeller for pumping a liquid flow medium disposed in the pump chamber and a shaft seal arranged in an inner radial area for sealing the dry space with respect to the flow medium, a seal carrier is provided with a guide structure by which fluid flow medium is conducted from an outer radial area to an inner radial area for directing flow medium into the seal for lubrication and cooling of the seal [24].

In addition, coolant circuit for engines with bypass line recently developed in United States of America. This coolant circuit could be applied for huge machines like vertical sea water pumps. The coolant circuit includes an inlet line and an outlet line. The coolant circuit further includes a heat exchanger with a plurality of heat exchanging elements. The coolant circuit also includes a bypass line disposed in parallel to the heat exchanger, between the inlet line and the outlet line. A control valve is disposed in the coolant circuit regulating the flow of a coolant, such that the coolant flows through the heat exchanger and the bypass line when the control valve is in a fully open position [25].

III. Result and Discussion

In this part, a case history about detecting Cavitation in sea water vertical Centrifugal lift Pumps explained in details.

Case history: sea water lift pump
PJ- 3-P-2102A Thursday, August 23, 2012:

The sea water pump was not equipped with any on line vibration monitoring system therefore traditional vibration measuring programs performed in three main points, two points related to electromotor ball bearings and the third point was related to first bush bearing of pump. Other locations were not accessible for condition monitoring activities. Schematic of sea water pump three vibration-monitoring points represented in Fig. 5. Besides, all vibrations measured in three main directions (horizontal, vertical and axial to the main shaft).

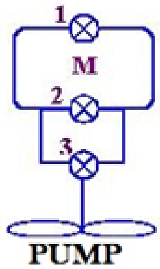

Fig. 5 Schematic of sea water pump three vibration-monitoring points

The vibration limits calculated based on the standard ISO2372 (BS 4675, VDI 2056) tables. These tables work on the basic principal of machine foundation types (flexible or rigid) and size of equipment (represented by machine KW). The KW of electromotor was found from its technical documents then replaced in mentioned tables on the standard ISO2372 (BS 4675, VDI 2056) in flexible foundation category and Table I obtained.

TABLE I
Sea Water Vertical Pump Vibration Limits

Vibration Limits			
Location	**Good condition**	**Alert condition (fair)**	**Danger condition(rough)**
Driver – motor	**less than 4.5m/s**	**between4.5-11mm/s**	**Above 11mm/s**
Driven – pump	**less than 4.5m/s**	**between4.5-11mm/s**	**Above 11mm/s**

There was no radial sudden movement that sometimes happens in these kinds of equipment but the vibrations data was increasing too much during latest two days. The maximum data from vibration trends during last 6 months was 2.3 mm/s rms in electromotor and 1.8 mm/s rms on pump bush bearing but now the vibrations reached 4.8 mm/s rms in electromotor and 2.3 mm/s rms in pump bush bearing. Highest amplitudes measured data represented in Table II.

TABLE II
HIGHEST AMPLITUDES MEASURED IN SEA WATER VERTICAL PUMP

Highest Amplitudes Measured						
Position	**Type**	**displacement in micrometer p-p**	**Velocity in mm/sec (r.m.s)**	**Acceleration (mm/s2)**	**Location**	**health condition**
Driver	**electro motor**	**22**	**4.8**	**4.7**	**electro motor**	**Not permissible**
Driven	**pump**	**10**	**2.3**	**5.5**	**pump**	**Not permissible**

The vibration data increased considerably during latest two days therefore the following maintenance activities recommended for this equipment.

Due to the high amount of acceleration on none drive end (NDE) and drive end (DE) bearings of electromotor in current situation and also the high frequency shape of FFT and bearing impact shapes in TWF it was recommended to change both bearings of electromotor. Both initial and current status of highest amplitudes measured FFT in electromotor shown in Fig. 6 (The blue diagram shows reference FFT and the black diagram shows current FFT).

Highest Amplitudes Measured TWF in electromotor that the bearing impact frequencies were dominated shown in Fig. 7.

The blade pass frequency dominated in pump FFT (5X) shown in Fig. 8 and we were suspicious about cavitation inside pump impellers. Then we performed an experimental cavitation testing.

We turn down the discharge valve and let the pump running in minimum flow.

Highest amplitudes acceleration measured both in pump and in electromotor reduced too much then we predicted that something chocked the strainer paths.

It is worthy to know that in maintenance activities some fish and sea creature's dead bodies sometimes remain in huge water flow paths coming towards the huge sea water pump filters and caused chocking.

This phenomenon caused reducing in suction pressure and strong cavitation in impellers. Then we strongly recommended checking the strainer for any probable chocking.

The strainer was chocked Overall vibrations reduced too much in all points and directions after opening the strainer and the vibration status of machine shifted to good condition.

In addition, it was recommended to circulate the suction filtering systems two or three times by modifying new filtering system equipped with some additional centrifugal pumps and flexible huge tubes to prevent cavitation in future pumps operations.

TWF of cavitation have a basic sine form that is because of unbalance due to impeller corrosion that mix with impact of bubbles to casing surface called modulation (Fig. 7).

Besides, cavitation showed itself usually in blade pass frequency in FFT (5X in our sea water pump shown in Fig. 8) [14].

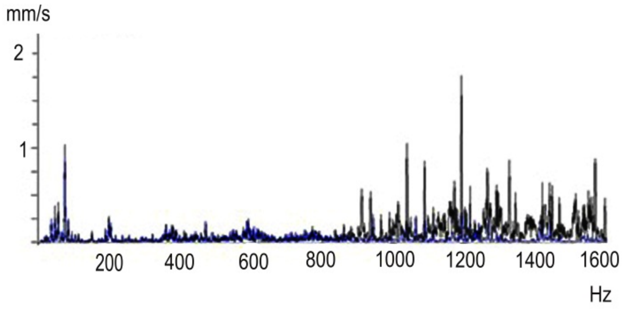

Fig. 6 Highest Amplitudes Measured FFT in electromotor

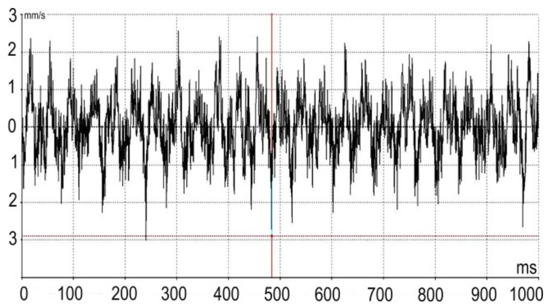

Fig. 7 Highest Amplitudes Measured TWF in electromotor

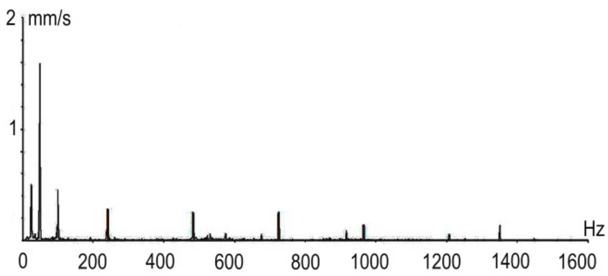

Fig. 8 Highest Amplitudes Measured FFT in sea water pump

IV. CONCLUSION

Cavitation is one of the common faults in all centrifugal pumps especially in industrial plants that pumping fluids characteristic such as inlet and outlet pressure and temperatures is hard to control perfectly, like petrochemical factories or oil industries. In such cases, modifying a balance line between suction and discharge could reduce the cavitation in future process operations. The dimension of balancing line and its diameter should be properly design and modify to reduce the vibration and noise. This kind of modification usually should be performed by some specialist from centrifugal pump vendor or manufacturer.

In addition, cavitation may occur in sea water centrifugal vertical pumps. In such cases, cavitation usually shows itself in blade pass frequency. Moreover, the amount of vibration trends increasing suddenly in vibration monitoring system of sea water pumps. Checking the strainer path for probable choking may help us a lot to solve or reduce both vibration and noise. Besides, it is strongly recommended to circulate the suction filtering systems two or three times by modifying a new system equipped with some additional centrifugal pumps and flexible huge tubes to prevent cavitation in future sea water pump operations.

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