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Diagnosis and Vibration Diminishing in Pump Operation

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Abstract

Pumps being components of wastewater treatment systems, water supply systems and irrigation systems are exploited under a wide range of operating parameters. User requirements make these equipments to work with functioning parameters close to the limit values recommended by the manufacturers, on low energy efficiency regime. In this manner vibrations occur during operation, which could be under specific rotation, different pump characteristics, dynamic or static load.
The present paper would like to emphasize by measurements the vibrations arising from pumps operated at low speeds, to establish dependency relations. Diagnosis of the phenomena is mandatory because it generates malfunction, damage and even pump or system failure.
Results obtained and their interpretation are the scientific base for improvement method technical recommendations, for process automation and service programs creation in order to ensure reliable operation and to help repair cost decreasing.

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Keywords: pump; operation; parameter; destruction; technical solution

1. Introduction

Pumps are basic active equipments that operate either water supply, or sewage, irrigation, drainage systems. In operation, the requirements imposed on such equipment are varied, leading to system functioning outside

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recommended regime. Analysis of operating parameters shows that the pumps can function with maximum efficiency, but near their edge they are exploited in cavitation or instability regime [1].

The pump operation at low flow and high hydraulic head involves the occurrence of important and quick variations accompanied by vibrations inside pump and transport structure [2]. Unfortunately, in most cases vibration associated with pump operation are taken into account only when it leads to negative effects, as excessive noise, damages, premature fatigue, and equipment failure [3]. Mechanical, hydraulic and peripherical causes are vibration source in centrifugal pumps; there are studies showing that vibrations are mainly generated by mechanical and hydraulic unbalance and have major effects on pump performance [4].

Pumping large aggregates are fitted with vibration sensors that monitor continuously, but they do not operate at low flow rates [1]. Operating range at low flow range is basically uncovered by this kind of behaviour monitoring.

Theoretical study of fluid flow through pumps is difficult, complex, and, in current practice, there are adopted simplified methods. All those options highlight the existence of non-permanent movement or pressure shocks materialized in mechanical processes [5].

From the mathematical point of view, a pumping unit is completely described by means of four equations (rotor dynamics, conduit pressure equation, moment and flow of the pump) [6]. Pump behavior modeling using transfer functions can be achieved only if the pump functioning is around the pump and system operating point [7].

In the triangle of velocities at constant speed, peripheral velocity, $u_{1,2}$, direction and magnitude, relative velocity, $w_{1,2}$, direction and β angle remain constant in operation. So, when flow, Q, changes the absolute velocity, $c_{1,2}$, vector modifies generating hydraulic shock especially at the rotor entrance.

In the case of semi-real impeller mathematical model analysis the axial the vortex occurrence into the rotor channel involves velocity diversion at the entrance and at the exit accompanied by the absolute velocity vectors change, $c_{1,2}$.

When changing the pump rotation, the size of the peripheral velocity, u, involves changing c vector change and hydraulic shocks generation.

Variation of input conditions due to operating parameters Q and H, variation of axial vortex and of pump driving rotation level implies absolute velocity vector change, especially at the rotor entrance. That assumes the appearance of additional energy loss, impaired cavitation properties alteration and of hydraulic shocks due to instability and cavitation phenomena.

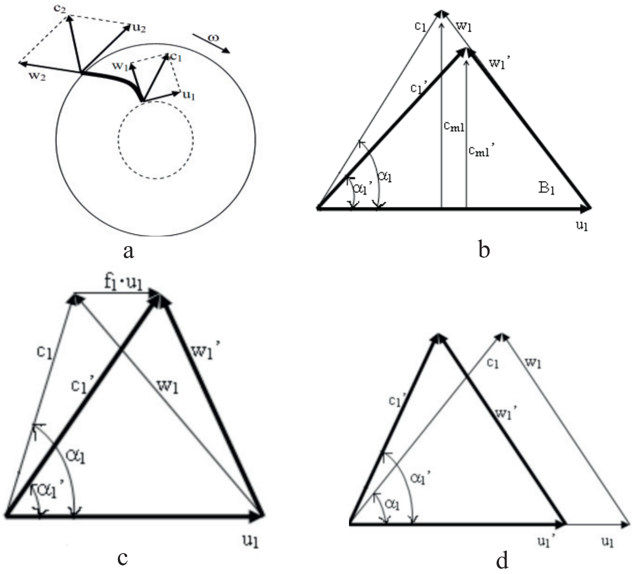

Fig. 1. Theoretical pumps study: (a) Speed of the centrifugal pump impeller: u – peripheral velocity ; w – relative velocity; c – absolute speed; ω - angular velocity; (b) Amendment of velocity triangle at the rotor entrance when flow changes; (c) Amendment of velocity triangle due to axial vortex; (d) Amendment of velocity triangle due to pump rotation change.

Operation to limit under cavitation or instability regime involves impermanent fluid flow regime and pressure shocks evidenced by noise and vibration [8]. Pump noise and pressure pulsation measurements demonstrates pulsating impermanent regime developed under cavitation regime and under low value flow under instability regime. Depending on requirements and desired results it can be choose between 3 options for vibration measurements performing [9]; the present study adopted the response measurement at the system exit and time dependence recording.

In order to regulate the pumped flow pumped it is possible to adopt internal and external methods. It is aimed to achieve the regulation involving minimal additional energy consumption.

To ensure efficient energy regulation, pump manufacturers produce equipment with flattened operating characteristics H = f (Q). This means that for pump hydraulic head small variations flow variations are significant.

Another efficient method of flow control supposes driving rotation adjustment. For pumps operated at variable rotation were revealed good returns when rotations were changed by ±10% for pumping static load installations or by ± 20% for pumping dynamic load installations. In terms of operators requirements those recommended limits are exceeded.

Dependence between pumps operating parameters and their rotation is expressed by similarity relations [5]:

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right)$$
$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \qquad (1)$$
$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

where:

$Q_{1,2}$ - pumped flow,
$H_{1,2}$ - pump hydraulic head,
$P_{1,2}$ - pump powers, corresponding to rotation n_1, n_2.

These relations are valid in case of rotor velocity triangles similarity.

2. Materials and experimental method

Measurements were performed in the Laboratory of pumps and pumping stations within the Faculty of Land Reclamation and Environmental Engineering – University of Agronomic Sciences and Veterinary Medicine of Bucharest (FIFIM-USAMVB). It has been used a GUND stand [10] dedicated to the study of centrifugal pumps operated at variable rotations. The stand is equipped with a LOWARA centrifugal pump having characteristics: Q = 10-50 l/min, H_p = 30.6-13.8 mH_2O, P_{me} = 0.68 kW, fitted with frequency static converter for rotation adjustment (fig.2).

The pump shaft rotation was checked by using optical rpm counter type DT Ebro 2236.

Pump outlet pressure pulsation determination were made by pressure sensors, interface and oscilloscope HM 15 Gund, and the noise level determination by sound-meter CA 834.

Vibration measurements were performed using vibro-meter Rionha vm-63a.

Vibration measurements were made for functioning points obtained on the characteristic operation curves corresponding to 3 different rotations, maintained constant. Also, here were made vibration measurements for functioning points highlighted on a characteristic operation curve for an installation with static pumping load or with dynamic pumping load.

Fig. 2. Experimental stand for pump performance study (FIFIM-USAMVB Laboratory).

The values obtained were overlapped on noise and pressure curves obtained from previous research (Pressure shock measured in the pump outlet collar function operating regime – normal, cavitation, instability at low flow rates; Noise intensity increasing on cavitation regime) [11], in order to make correlations within results interpretation stage.

Measurements were performed to determine the characteristic curves for three values of pump speed (2000, 2400, 2700 rpm), on transverse and longitudinal direction of the pumping unit shaft, for different operating points. Measurements were conducted both for static (constant pressure on discharge pipe by closing it and velocity dropping) as well as dynamic hydraulic adjustment (discharge pipe open and velocity dropping). Measured characteristic elements are vibration displacements, velocities and accelerations.

Results were checked on average power pumping stations installed in water distribution systems.

3. Results and discussion

Results are presented in graphical form and are overlapped on those values calculated by means of similarity relations.

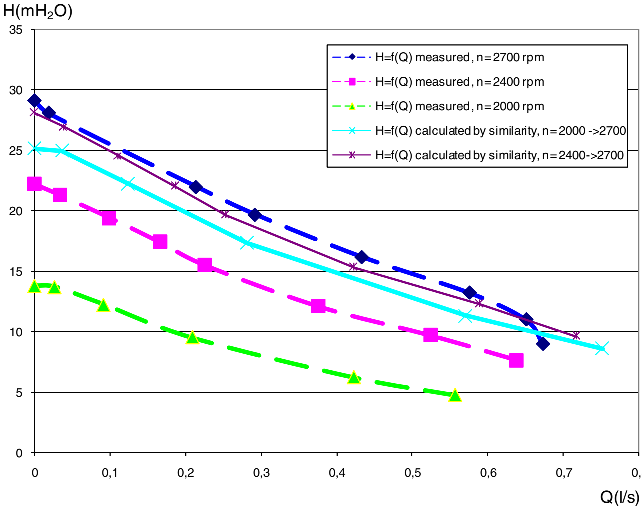

Fig. 3. Operating characteristics H = f(Q).

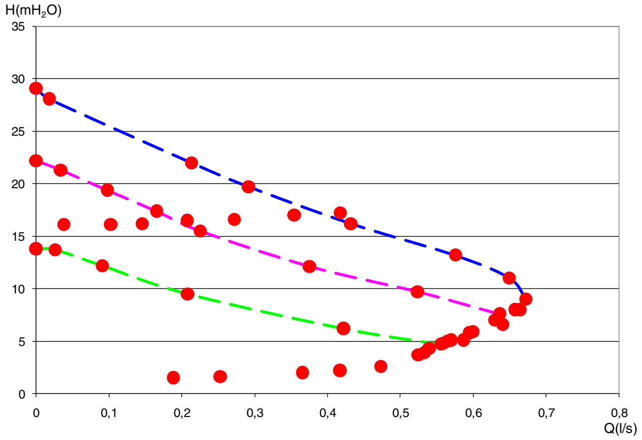

Fig. 4. Operating points selected for vibration measurements.

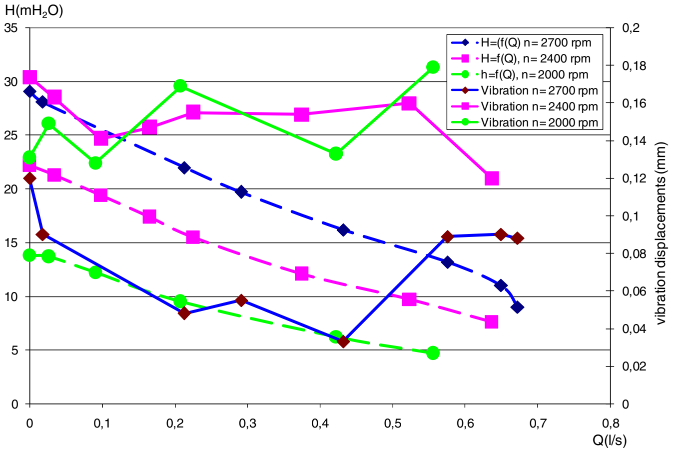

Fig. 5. Transverse vibration maximum amplitude obtained when driving pump rotations decrease.

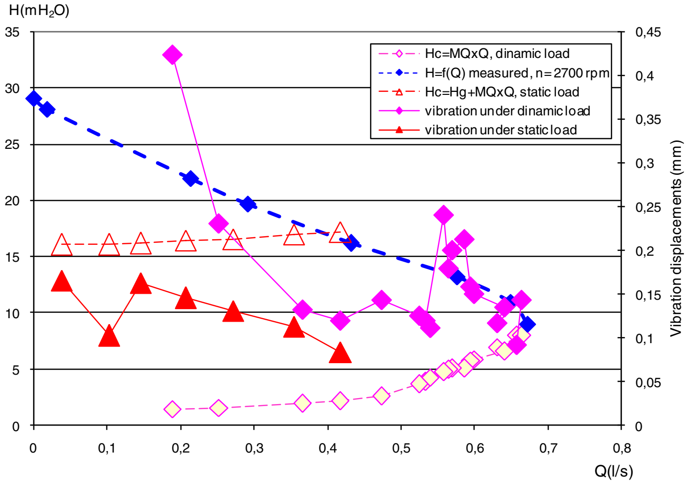

Fig. 6. Transverse vibration maximum amplitude obtained for static load pumping installation or for dynamic load pumping installation.

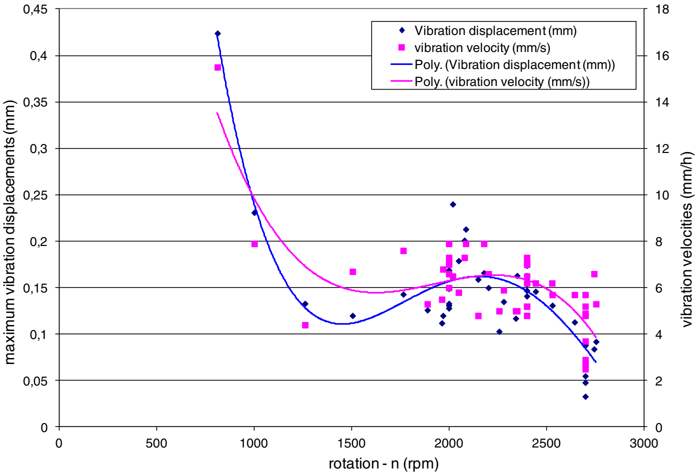

Fig. 7. Transverse vibration amplitude and velocity depending on driving pump shaft rotation.

Laboratory measurements for centrifugal pump studied highlight that under analyzed rotation the similarity relations are not satisfied due to failure of meeting the geometric similarity of velocity triangles. Characteristic angles in those triangles are not congruent for the rotor entrance absolute velocity c1 and therefore shocks occur joined with the highlighted and calculated energy losses.

Increasing energy losses through widely changing rotation involves the development of mechanical processes and noise, vibration and pressure pulsations appearance.

It is imposed the monitoring of such phenomena, quantification and adoption of measures to reduce equipment attrition and to increase the process economic efficiency.

Pumping installation exploiting within sewage systems is performed in a wide range of operating parameters due to conditions imposed by flow changing and to technological requirements imposed on the wastewater treatment process.

Wastewater treatment plants are designed and produced to fulfill the operation and efficiency conditions of under loads evaluated according to serving society dynamics Under these conditions are operated wastewater supply pumps and recirculation pumps, whose capacity should provide water volume from 100% up to about 400% of the inflow, according to wastewater treatment pathway and efficiency desired.

In these conditions, the pumps are exploited under wide operating parameters and there are applications where equipment recorded high levels bearings attrition.

The results point out the increasing vibration amplitude with rotation reduction under cavitation regime and under low flow.

Transverse vibration maximum amplitude occurs especially on those installations with dynamic pumping load in low flow domain or under early cavitation regime.

Velocity curves determined for transverse vibrations have similar shape with displacement curves.

Vibration amplitude measured in the axial direction does not point out the significant values and modifications.

For measured velocities and vibration amplitudes is highlighted a significant increases with rotation reducing.

4. Conclusion

Pumping aggregates are complex equipments that convert mechanical energy into hydraulic energy. In pumps functioning there are regimes when the energy consumed is transformed into other forms of mechanical energy materialized in noise and vibration.

These pumping aggregates vibration raising involves attrition and maintenance costs increasing. High capacity pumps with long shafts require vibration monitoring depending on requires operating regime system and need avoidance methods to be deployed.

High level vibrations are registered under cavitation regime or instability regime or in the case when widely reducing driving pump rotation.

When the pump operation involves widely flow adjustment using variable rotation drivers it is recommended the adoption of mixed methods:

- in the case of pumping stations for raw water supply (wastewater treatment plants) it is encouraged the flow control through variable rotation driving combined with by-pass duct adjustment; therefore rotation reduction is limited as well as the total pumped flow; automation system controls bypass pipe valve opening at a rotation preset level corresponding to the minimum wastewater reception tank level

- in the case of recirculation pumping stations with dynamic load it may be identified the following situations:
    - pumps for external recirculation that convey sludge from secondary settler in biological reactors do not require wide flow changes (except the operation on heavy rainfall); flow control is achieved along with the control provided by the internal recirculation pump stations;
    - internal recirculation pumps require widely flow changes corresponding to values from 100-300% of the inflow; in these conditions the restriction for driving rotation reduction is achieved by adopting pumping stations equipped with a larger number of pumps or timing pump operation based on a predetermined schedule function on the raw water volume admitted into the wastewater treatment plant and the desired treatment efficiency.

We intend to continue our research by recording vibration and interpreting results after vibration sensors mounting to pumps in water supply and sewage systems. This type of operational data support optimal operation parameters setting in order to prevent pumping aggregates destruction.

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