EVALUATION OF VIBRATORY BEHAVIOR AND MAINTENANCE FOR MISALIGNMENT OF CENTRIFUGAL PUMPS

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The vibrations diagnosis process allows an estimate of the operating condition of the dynamic equipment items via measuring both the vibrations and some other process data. Maintenance is a complex of technical and organizational activities aimed at keeping the equipment in good operating condition by the maintenance and repairs in case of defects of industrial systems. The misalignment of the machines and equipment is one of the causes generating vibrations and it constitutes a major defect which is hard to identify and fix. The theoretical and experimental investigation of the vibratory behavior of centrifugal pumps (for clean water) in case of a misalignment defect is an important and actual issue. A modern theoretical method for the achievement of the conformity of the geometrical dimensions of the pump and the vibrations amplitude (determined by experimental measurements), vibrations caused by the misalignment defect, is an up-to-date, new and original matter of research.

Keywords diagnostics: maintenance, vibration, misalignment, centrifugal pumps

1. Introduction

The evaluation of the vibratory behavior and the maintenance actions allow early defects to be detected and fixed, with no need to stop operating or disassemble certain pieces of equipment. The vibrations of rotating components or assemblies are transmitted to the neighboring parts too, with a harmful impact on the operation of that machine or equipment.

Major defects in dynamic rotating equipment items are rotor unbalance and misalignment. Misalignment is an incongruity of coaxially of two or more machines, which are coupled together by means of rigid or flexible couplings (rotational axes of the machine are not on the same line) [1]; [2].

The purpose of the conducted research is the evaluation of the operating and maintenance condition of the centrifugal pump ABS Z 22-350/350/45, in terms of vibrations generated by the following potential defects: loose foundation screws

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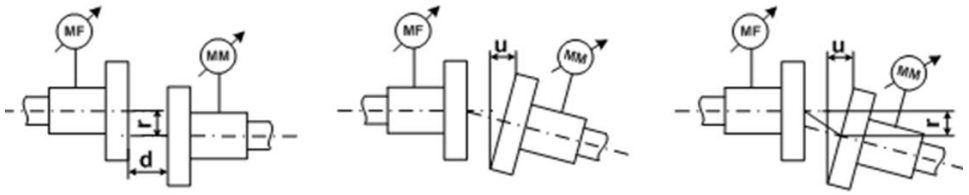
(defect also known as "soft footing" in the technical literature), the wear of the rotor, slack and faulty roller bearings. Vibrations due to these defects conveyed throughout the entire structure of the pump and enhanced during its functioning. Therefore, the spectral analysis of vibration components proves to be mandatory.

The theoretical and experimental investigation of the vibratory behavior of the centrifugal pump (for clean water) in case of a misalignment defect is an important and actual issue. A modern theoretical method to achieve the conformity of the geometrical dimensions of the pump with the vibrations amplitude (determined by experimental measurements), vibrations caused by the misalignment defect, is an up-to-date, new and original matter of research.

2. General Notions

The main factors influencing the misalignment are: how the machines are anchored to the foundation, the thermal expansion, the weight of the pump, the maintenance operations. The misalignment is divided into two components: the radial or parallel misalignment and the angular misalignment [3], [5]. When the radial and the angular misalignment occur simultaneously, they result in a combined misalignment, as shown in Fig.1c. Figures 1 a, b, c show the three types of misalignment. [3], [5].



a. Radial misalignment b. Angular misalignment c. Combined misalignment
Fig. 1. Types of misalignment [3],[5]

The misalignment of the machines occurs in vertical, horizontal and axial line, in the couplings. The *soft footing* defect occurs when the soles of the machine do not lie on the same level as the base plate or the foundation of the machine. The *soft footing* changes the position of the machine shaft and cause the rotor misalignment or unbalance.

Detecting the "soft footing" defect can be done by means of a dial gauge fastened to the machine sole or by attaching the alignment kit to the coupling.[1]

By means of the specific instruments for the measurement of vibratory behavior it is possible to monitor the *operating condition* of every dynamic piece of equipment, with no need to shut down the process line in the most ill-suited circumstances.

3. Experimental plan of research

The purpose of this case study was to identify and prevent (by means of vibration measuring and vibration analysis equipment) any wear and malfunction of the mechanical components and, particularly, any parallel misalignment of the component parts of the centrifugal pump Z 22-350 ABS / 350/45 (horizontal single-stage-pump for clean water).

The areas of use of the monitored pump are as follows: water supply systems for cities, towns and villages; water supply systems for residential and high-rise districts, for shopping malls, office buildings; industrial facilities; fire fighting water supply systems; irrigation water supply systems.

- *The characteristics of the monitored pump ABS Z 22-350/350 – 45,* as per Fig.2 a, are: maximum flow: 1100 m^3/hr; maximum pumping height: 45 m; motor type Dutchi DM1 315 LX 4: 220V or 380V; maximum power: 200 KW; maximum temperature of the pumped fluid -10°C - + 90°C; average temperature -10°C - + 40°C; pump frame type 06; coupling N – Eupex B 200; rotor type 417; types of the four ball bearings: SKF 6319; NTN 6319; FAFNIR 6313 and FAG 7313 B; rotor rotation speed: 1480 rpm - variable.[4],[5]

a) Assembly pump, coupling, motor b) Subassembly of the coupling replaced in case of misalignment

Fig. 2 Centrifugal pump ABS Z 22-350/350/45 [4],[5]

In case of great misalignment, the coupling subassembly will be replaced as shown in Fig. 2 b.

- *Place of the survey*: The water supply and sewerage company "S.C. Apă Canal 2000 S.A.", Department Smeurei.
- *Experimental devices and measuring methods used in conducting the survey*. The monitoring of the operating condition of the pumps was conducted by measuring the vibrations with a vibration analyzer (Fig.3 a) type Easy-Viber, series 104701 (available in the inventory of the „S.C. Apă Canal 2000 S.A."), and with piezoelectric pick-ups (T_a, T_v ,T_h) with magnetic fixture, type VMI-AB Sweden. *The employed software was the product SpectraPro - Sweden.*
- *The definition of the measure points and the measuring directions* are

shown in Figure 3 a, b, c.
Broadband measurements were the subject of evaluation and were carried out either on the bearing casings or on other parts of the pump which have a significant reaction to dynamic forces and therefore are defining for the vibrations of the machine. In order to assess the response of the pump to vibrations, measurements were conducted along three lines: axial, vertical, horizontal.

- *Frequency range*: For the measured vibrations, a frequency range between 2 Hz - 3200 Hz was chosen. The selection of the frequency range was made under consideration of the recommendations in the ISO norms 10816-3, ISO 2372 for industrial machines with a nominal power of more than 15 kW and nominal rotation speeds starting from 120 rpm/on.

a) axial vibration measurement b) vertical vibration measurement c) horizontal vibration measurement

Fig. 3 Examples of vibration measuring points along the three lines and of the equipment used

Vibration measurements were carried out at the sole of the machine in an axial line or at the bearings in a vertical and a horizontal line.

4. Measurements conducted with SPECTRAPRO – Sweden instruments *(examples of obtained diagrams)*

As a result of the four series of measurements within the maintenance activities, diagrams were obtained and plotted in order to find out the following data: the trend of the vibratory behavior of the pump, the FFT spectrum ranges, the spectra of the waveforms or of the jacket forms for the four bearings or else on the for fastening the pump to the foundation. The maintenance of the centrifugal pump ABS Z 22-350/350/45 took place in four stages at the dates as detailed in the diagram in Fig. 4, where we can notice the presence of harmonic 2 x RPM on the three measurement days, namely: 07.02.2011; 05.04.2011; 06.07.2011, pointing to a misalignment, which vanishes after its alignment by means of the Laser kit on the 04.08.2011.

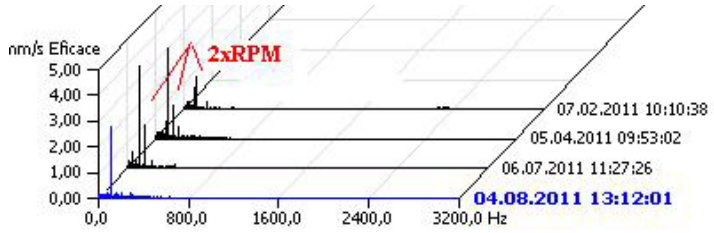


Fig.4 FFT diagrams for the four maintenance measurements

Following the measurements conducted in view of the diagnostic, it could be noticed that the harmonics 4 x and 5 x RPM represent the prevailing frequency of the spectrum. This fact was also sustained by the presence of the harmonics of this frequency in every spectrum.

The following results became obvious on the occasion of the detailed diagnostic which proved to be mandatory due to the presence of wide amplitude spectrum components:

On the electric drive motor there are significant axial vibrations which pointed to the following defects: misalignment of the motor – pump axis; faulty position of the shaft in the bearings; excessively loose bearings.

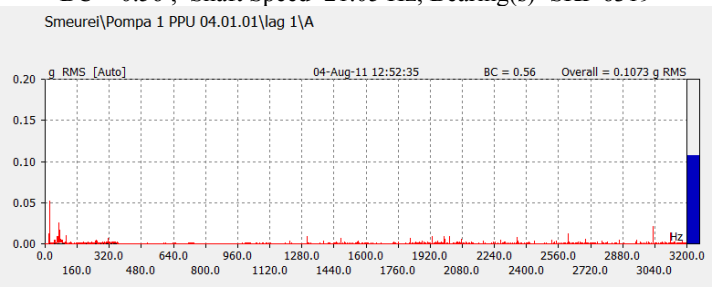
- *Compensation remedies taken to the centrifugal pump ABS Z 22-350/350/45*

At the company „S.C. Apă Canal 2000 S.A.”, after the diagnostic and maintenance report, the alignment of the flexible coupling of the pump was performed with the Laser kit, a normal operating duty of the pump (suction and discharge pressure, flow rate) was ensured, the ball bearings were adjusted, etc.

In Fig.5 there are submitted examples of diagrams obtained in the last maintenance stage, after the misalignment fault was corrected.

SPECTRA REPORT

Smeurei\Pump 1 PPU 04.01.01\lag 1\A\Measuring date :04-Aug-11 12:52;
Total value = 0.1073 g RMS;
BC = 0.56 ; Shaft Speed=21.05 Hz; Bearing(s)=SKF 6319

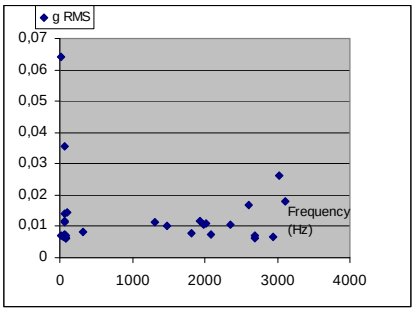


a)

b) Table of 30 common peaks and acceleration measured

No	Freq. (Hz)	g RMS
1	21.06	0.0643
2	69.67	0.0356
3	3032.50	0.0263
4	3117.22	0.0180
5	2608.89	0.0167
6	105.23	0.0144
7	61.23	0.0140
8	1931.14	0.0119
9	71.86	0.0118
10	1304.83	0.0115
11	67.58	0.0114
12	2015.86	0.0109
13	1990.92	0.0107
14	2354.73	0.0104
15	1474.27	0.0100

No	Ferq. (Hz)	g RMS
16	315.65	0.0084
17	1821.47	0.0079
18	2075.64	0.0076
19	64.29	0.0074
20	77.83	0.0072
21	18.37	0.0071
22	46.83	0.0070
23	2694.37	0.0069
24	62.79	0.0069
25	49.25	0.0068
26	2947.78	0.0065
27	2693.67	0.0063
28	81.17	0.0063
29	76.45	0.0063
30	80.25	0.0060



c)

a) The FFT diagram for the accelerations measured on the bearing 1, after the correcting steps of the defects of the centrifugal pump *ABS Z 22-350/350/45*;
b) Table of the 30 frequency and acceleration peaks measured by means of the SPECTRAPRO-Sweden equipment;
c) Diagram of the measured accelerations

Fig.5 Examples of diagrams and tables with values of the frequencies and accelerations measured in the bearings in the final maintenance stage, after the faults had been remedied

5. Theoretical investigation for the correction of the misalignment fault caused by vibrations.

After the maintenance works have been completed, it is imperative to carry out a re-checking of the parameters of the centrifugal pump and to compare the new values of the measured vibrations with the limits prescribed be the Romanian standards - STAS. For the misalignment, the re-measured values have to be compared with the ones prescribed by the producer. The said parameters may be checked also by theoretical methods.

The theoretical investigation method applied within this survey was aimed at the achievement of a tridimensional model of the centrifugal pump ABS Z 22-

350/350/45, via a simulation in the program CATIA - V5 R16 and a numerical analysis of the misalignment in the program ANSIS-12.0.1

In view of the numerical analysis in the program ANSIS-12.0.1 the moment of force caused by the measured vibration were calculated in the coupling during the last maintenance stage, after completing the alignment with the Laser kit, and the following stages were covered:

1) The maximum values were chosen for the accelerations measured on the three lines – axial, vertical and horizontal, from the diagrams obtained through measuring the vibrations by means of the SPECTRAPRO Sweden equipment and program.

2) The forces were calculated (in the three lines, F_p for the pump, F_m for the motor)

$$F_p = m_p \bullet a_p \text{ (N)}; \qquad F_m = m_m \bullet a_m \text{ (N)} \tag{1}$$

where: m_p (kg) = mass of the pump; m_m (kg) = mass of the motor

a_p = maximum acceleration of the pump (mm/s^2) on the three lines;

a_m = maximum acceleration of the motor (mm/s^2) on the three lines

3) The moments of force were determined for each couple of the coupling pertaining to the pump, M_p, or to the motor, M_m:

$$M_p = F_p \bullet r \text{ (N mm)}; \qquad M_m = F_m \bullet r \text{ (N mm)}; \tag{2}$$

where: F_p= the forces for the pump on the three lines;

F_m= the forces for the motor on the three lines;

r = the radius of the couples of the coupling

4) A simplified model of the centrifugal pump was made, observing the dimensions prescribed by the designer, in the 3D designing program CATIA V5R16, as shown in Fig.6.

5) This model was imported into the program ASNSIS-12.0.1, and the values determined previously according to the proposed algorithm were entered, and then they were analyzed under static conditions.

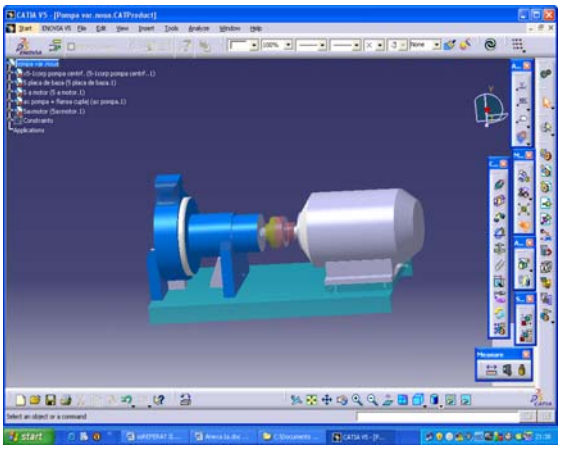


Fig. 6 Model of the centrifugal pump ABS Z 22-350/350/45 in the program CATIA V5R16

Fig. 7 shows the model of discretization. Fig. 8, 9 shows the determined moments of force entered into the ASNSIS, for the motor and for the pump.

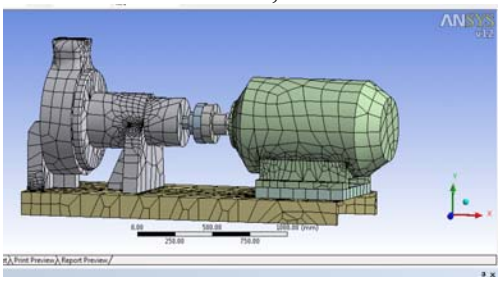


Fig.7 Model of discretization

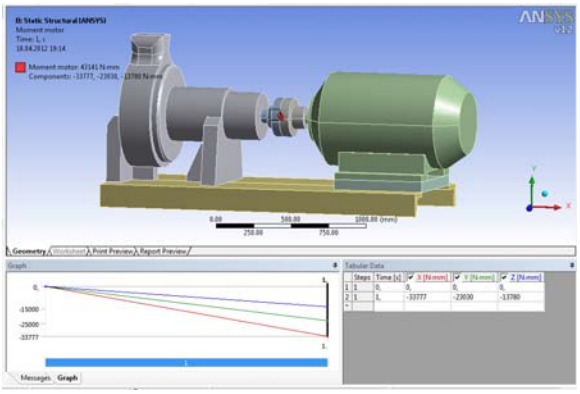


Fig.8 Application of the moments of force generated by the vibrations and determined for the motor

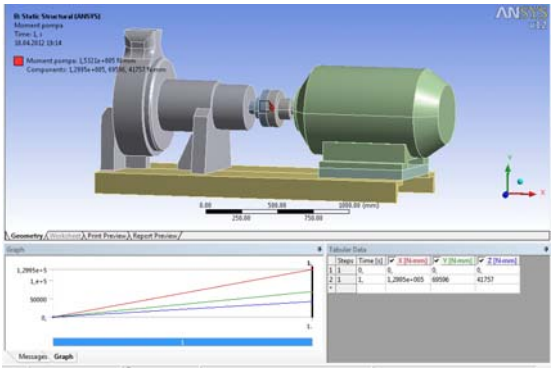


Fig.9 Application of the moments of force generated by the vibrations and determined for the pump.

Fig. 9 offers the reading of the misalignment values analyzed under static conditions in the program ANSIS-12.0.1. The obtained maximum value is 0.0014096 mm.

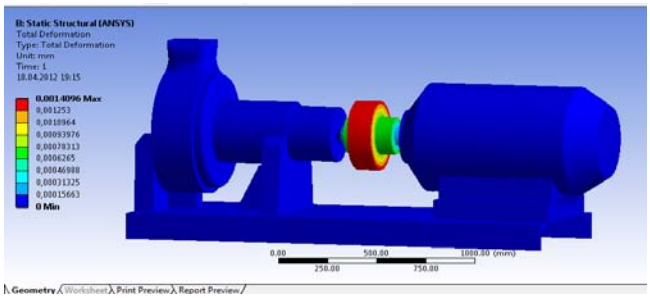


Fig.9 Structural static diagram in the ANSIS-12.0.1

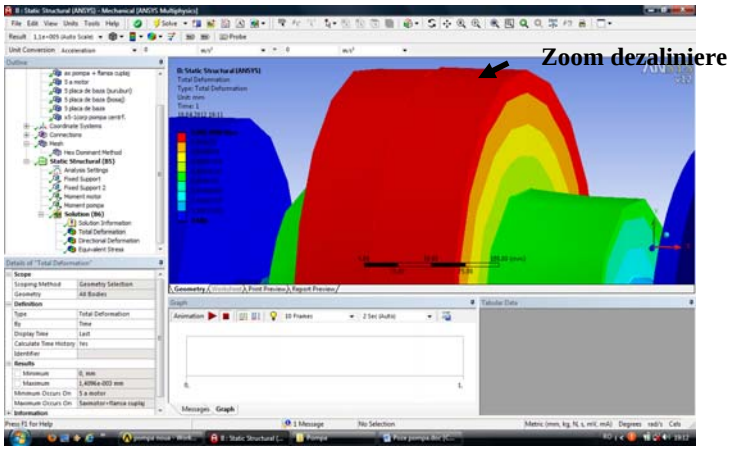


Fig.10 Zoom highlighting of the misalignment in the coupling area

The same figure is pointed out as optimum value by the producer (Messrs. SIEMENS), too, of the Flender N-Eupex B 200 type elastic coupling included in the construction of the centrifugal pump ABS Z 22-350/350/45.

6. Conclusions

- The investigation of the vibrations generated during the functioning of machines or equipment items is required in order to determine and fix the faults that might cause a catastrophic wear and the shutdown of the equipment.
- *The theoretical misalignment simulation method by means of the program ANSIS - 12.0.1, proposed by the authors in this survey, is an original contribution, as it allows to match the geometrical dimensions of the centrifugal pump with the amplitude of the measured frequencies and accelerations (in case of vibrations), during the four stages of maintenance.*
- *It is necessary for jointly preparing the maintenance documentation by the two companies: the customer and the maintenance provider.*
- *It enables the designer to act upon the dimensions of the pump so as to grant*

its optimum operation.

- The maintenance activities carried out at the centrifugal pump analyzed during this survey allowed the company "S.C Apa Canal 2000 S.A." to fix the coupling misalignment defect caused by vibrations with no need to interrupt the operating process.
- Thus, repair action time and expenses were saved and this allowed the life-time of the pump to be extended.
- In view of keeping the centrifugal pump ABS Z 22-350/350/45 functioning within its original operating parameters it is recommended that, for another maintenance stage, an analysis of the thermal expansion be also performed for the coupling.

Acknowledgments

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