Development of a vibration monitoring system for optimization of the electrical energy production

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Abstract— This article presents the development of a vibration monitoring system based on the method of spectral analysis at a strategic facility such as a feed pump in a thermal power plant and that the aim of optimizing the production of the electrical energy. Indeed, the maintenance policy practiced before at the pumps has demonstrated its failure after recording several outages this facility resulting in huge production losses during the past 10 years. This method is limited to the overall vibration measurements at different levels of feed pumps and the irregularly then comparing these measured with reference values constituting the signatures alert and danger of these pumps. Thus, this method does not allow to identify possible causes of excessive vibration at different levels of the pumps. For cons, the new maintenance policy to establish the level of these pumps is a vibration monitoring to track the health of the system in operation and thereby detect any problems and trends in order to plan timely corrective actions.

Keywords: production optimization, spectral analysis, predictive maintenance.

I. INTRODUCTION

Most of the rotating machines produce vibration [1]. This is the result of the dynamic forces inside the machines which include rolling elements and inside the structures which are connected to the machine. The vibrations create fatigue; wear and they are often responsible for failure of the machine.

On its turn, the deterioration of function translates by changes in distribution of the vibratory energy leading usually to a major increase the level of the vibrations. Thus, while observing the evolution of this level, it is possible to get very useful information on the state of the machine and to reveal its level of wear [1].

This article describes the implementation of a vibration monitoring system of strategic pumps of a thermal power plant which failures were at the origin of enormous lost production in the past 10 years despite the existence of the redundancy of this installation. This call into question of failure of the maintenance policy currently adopted on those pumps which are restricted to irregulars factories of investigations of vibration levels and compare these with danger and alert thresholds without being able to identify the causes of those vibrations.

II. THE METHODS OF VIBRATION ANALYSIS:

A. Príncipe :

The principle of the vibrations analysis is based on the idea that the machines structures, excited by dynamic efforts, give the vibratory signals whose frequency is identical to the one of the efforts that provoked them; and the global measure taken in one point is the sum of the vibratory answers of the structure to the different excitatory efforts. The vibrations transmitted by the structure of the machine can thus be record via sensors placed at specific points and through their analysis it is possible to identify the source of efforts to which it is subject[1].

B. Methods :

1) Global measure :

It is an approximate method of the vibration analysis of signal which abstracts away from the frequency parameter to measure only evaluated amplitude in different ways; the amplitude can represent a displacement, a velocity or acceleration [2].

2) Shock Pulse Method :

These techniques are used for detection of bearing damage. In fact, the frequency generated above 2000Hz are the frequency which mainly due, on rotating machine, to bearing or gear damage excluding the imbalance defects, misalignment, electrical problems, etc [3].

3) Spectral analysis : [4]

It is a recording of vibrations spectrum emitted which links its peaks with the phenomena which have given rise. It helps to determine the potential damaged organs of the machine. It is a control with diagnosis.

The specter, tool of this analysis, is presented in the form of a graph which shows the amplitude of each frequency. The components of the vibration signal are represented in the form of the peaks which can be taken individually the variation of amplitude, as in the global measurement, without creating a « masq effect » which that threatens to not indicate a defect in development stage .

It is then possible from the characteristics of the machine being monitored and the frequencies refer to anomalies to detect the cause of the defect and monitor the evolution.

III. ANALYSIS OF THE DYSFUNCTIONS OF ALIMENTARY PUMPS:

Our study site is a thermal power plant with three units, each one is provided of two alimentary pumps (one in operation and the other is standby).

A. Description and technical characteristics of the alimentary pump:

The alimentary pump is a centrifugal pump, multicellular, coupled to a motor; it is designed to feed the boiler with water.

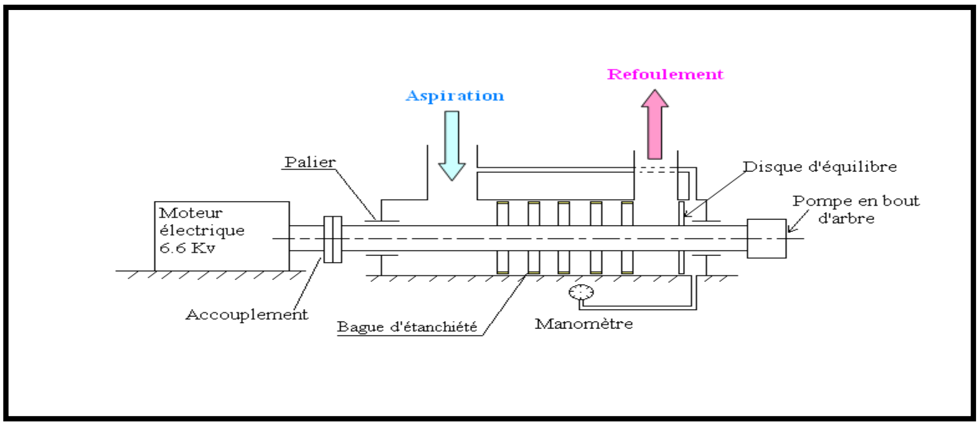


Figure n°1: Simplified schema of a feed pump

The pump unit consists of:

- Alimentary pump;
- Electric motor;
- Non-return valve and a recirculating system having a motorized valve with a fast-acting and a throttle device (diaphragm);
- Oil pump;
- Automatic device, instrumentation and control systems.

Main Technical Characteristics of the alimentary pump:

- Flow rate in m3/ h………………150
- Discharge pressure of water……165+ou-3%
- Feed water temperature (maximum)…… 160°C
- Pressure in the intlet pipe connections at t = 160°C in bar….6,4
- Outlet pressure of pump in bar ………………….160(Q = 270m3/h)
- Rotation speed in tr/mn ……………………………………2980

- Power absorbed (maximum) in KW…...................................1720
- Motor voltage in KV……………………………………….6,6
- Frequency in HZ……………………………………………..50

Figure n°2: Feed pump

IV. ALARM LIMIT FOR THE FEEDS PUMPS:

A. The scale used in thermal power plant is illustrated the following table:

Rotation speed in r/mn	Extra fine	very fine	very good	good	passable	little severe	severe	very severe
750	5,8	5,8 à 14	14 à 23	23 à 43	43 à 93	93 à 200	200 à 400	>400
1000	4	4 à 8,8	8,8 à 18	18 à 33	33 à 70	70 à 160	160 à 300	>300
1500	3	3 à 6,5	6,5 à 13	13 à 24	24 à 50	50 à 110	110 à 210	>210
3000	1,5	1,5 à 3,2	3,2 à 6	6 à 14	14 à 26	26 à 55	55 à 100	>100

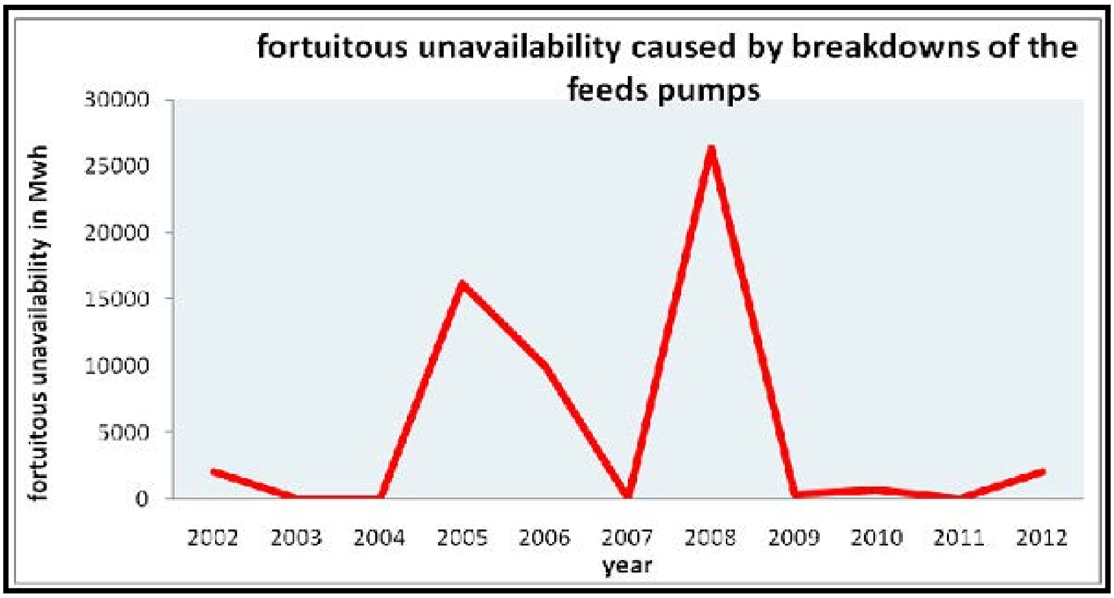
Table n°1: severity of vibration depending on the rotation speed

These incidents and breakdown of the pumps registered during these last 10 years occurred enormous losses of production (see tables &graphs below). These losses of production represent significant loss of income (see tables &graphs below) during 10 years about 28714,5 KDH (2871KDH/an).

These incidents were mainly manifested by excessive vibrations that causing failure and shear of different organs of the pumps (shaft, bearing, etc.) (See figure n°3&4 for incidents registered in 2005).

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Cumul
loss of production in MWh	1980	0	0	16144	9999	0	26345	360	650	0	2050	57429

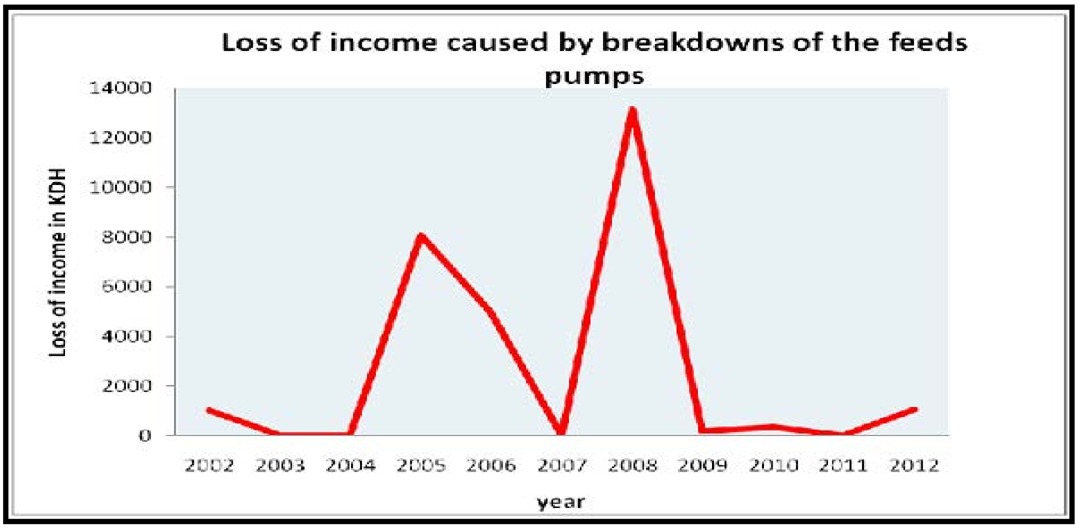
Table n°2 : fortuitous unavailability in electrical power caused by breakdowns of the feeds pumps during last 10 years



Graph n°1: fortuitous unavailability in electrical power caused by breakdowns of the feeds pumps during last 10 years

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Cumul
loss of income in KDH	990	0	0	8072	4950	0	13172.5	180	325	0	1025	28714.5

Table n°3: loss of income in KDH caused by breakdowns of the feeds pumps during last 10 years



Graph n°2: loss of income in KDH caused by breakdowns of the feeds pumps during last 10 years

According to the graphs above, the peaks of losses in electricity production or loss of income were registered in 2005, in 2006 and in 2008. So, the vibration levels detected on the date of the incidents recorded in 2005, 2006 and 2008 (see tables &graphs below) allowed that several conclusions can be drawn.

Figure n°3: Failure of bearing

Figure n°4: Shear of shaft

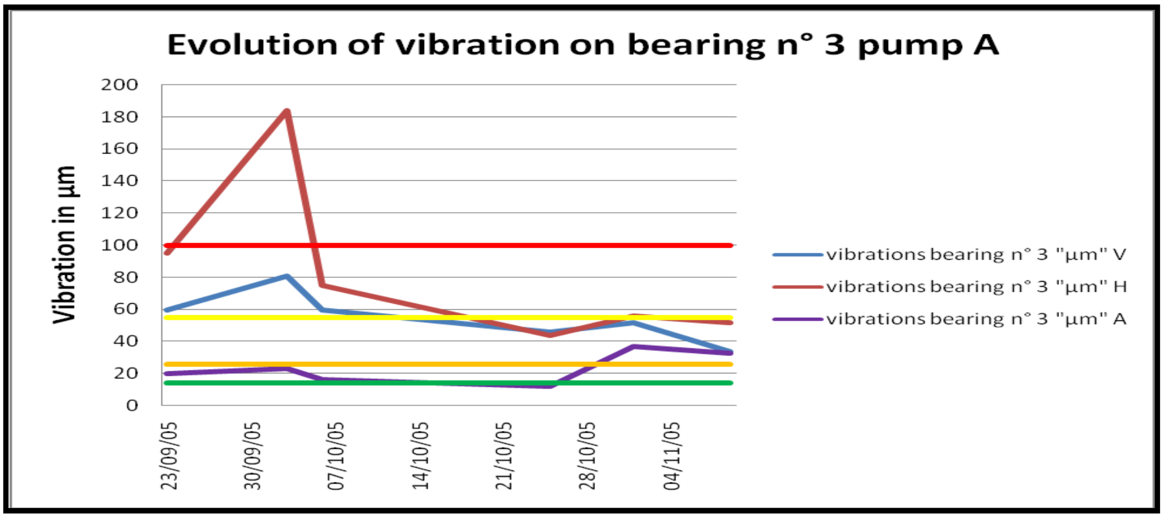
B. Analysis of the incidents in 2005, 2006 and 2008:

1. Incidents in 2005:

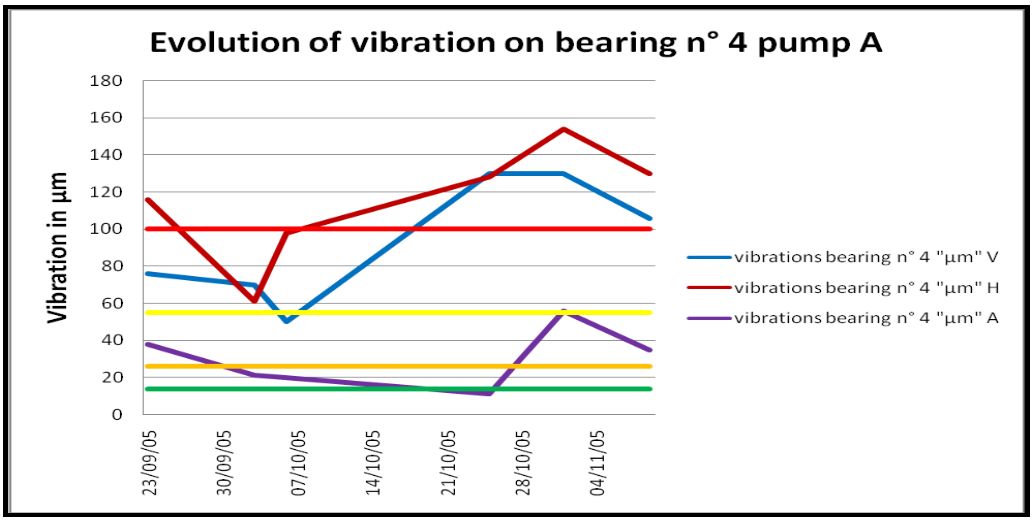
Evolution of vibrations of the pump A unit n°2

Date		23/09/05	03/10/05	06/10/05	25/10/05	01/11/05	09/11/05
vibrations bearing n° 1 "µm"	V	17	22	9	27	32	35
	H	19	17	30	20	31	27
	A	11	36	31	29	34	32
vibrations bearing n° 2 "µm"	V	15	23	26	15	17	31
	H	16	20	25	20	20	32
	A	33	32	24	14	17	27
vibrations bearing n° 3 "µm"	V	60	81	60	46	52	34
	H	95	184	75	44	56	52
	A	20	23	16	12	37	33
vibrations bearing n° 4 "µm"	V	76	70	50	130	130	106
	H	116	61	98	128	154	130
	A	38	21	20	11	56	35

Table n°4: vibration levels on different bearings of the pump B unit n°2



Graph n°3: Evolution of vibration on bearing n° 3 of the pump a unit n°2



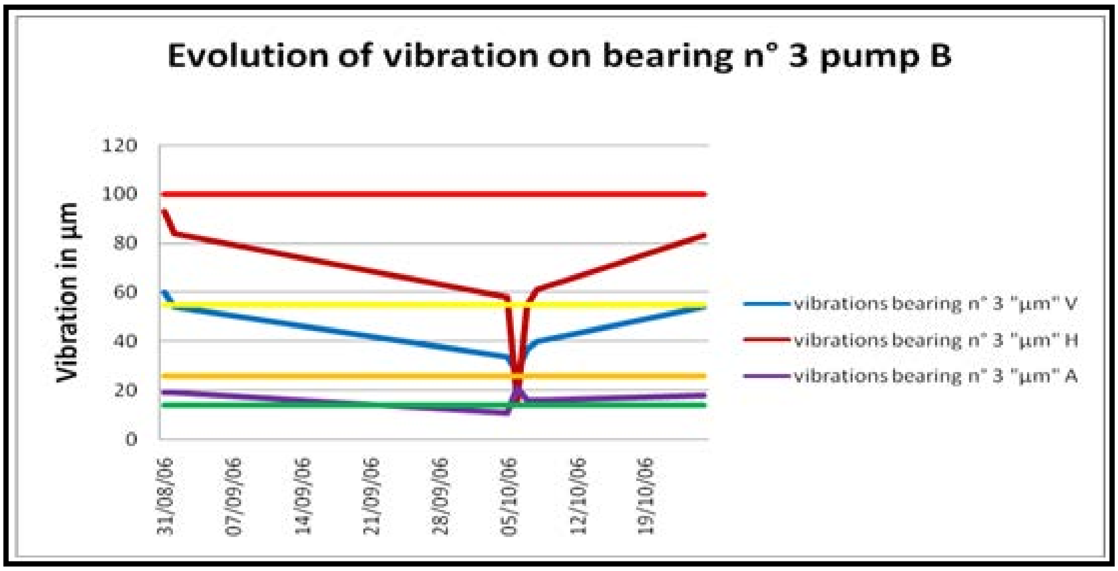
Graphe n°4 : Evolution de vibration sur palier 4 pompe A tranche n°2

2. *Incidents in 2006*

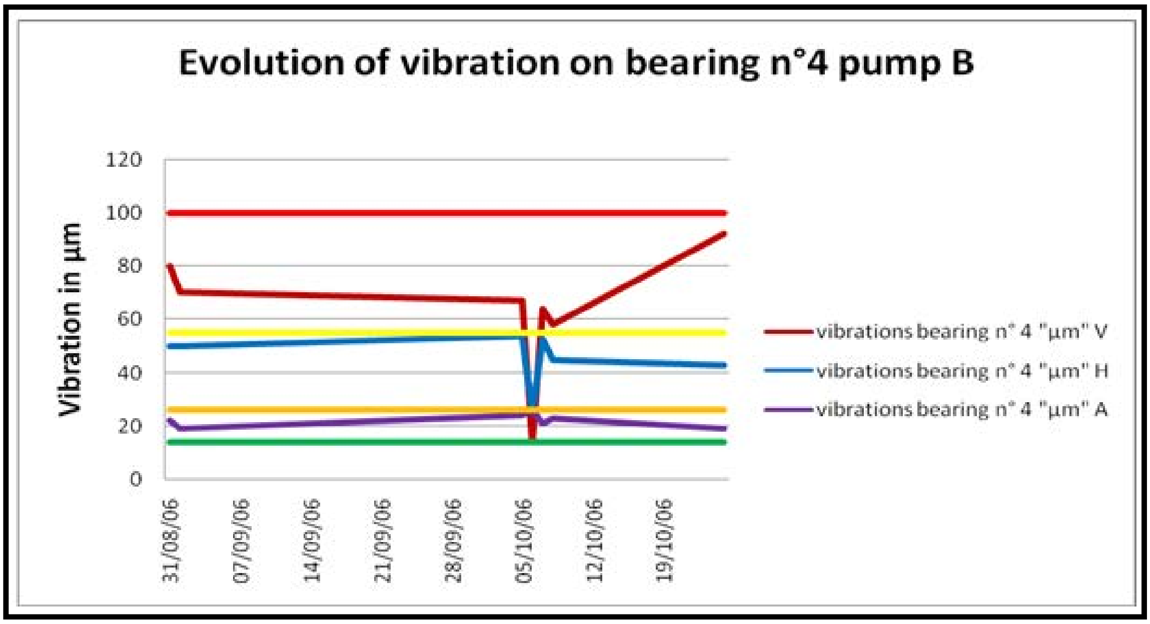
Evaluation of vibrations of the pump B unit n°2

Date		31/08/06	01/09/06	05/10/06	06/10/06	07/10/06	08/10/06	25/10/06
vibrations bearing n° 1 "µm"	V	15	17	12	61	27	36	11
	H	35	27	23	42	28	29	20
	A	31	36	25	29	39	50	19
vibrations bearing n° 2 "µm"	V	33	25	26	24	40	44	23
	H	8	8	10	45	13	22	12
	A	28	20	17	15	33	43	15
vibrations bearing n° 3 "µm"	V	60	54	34	28	37	40	54
	H	93	84	58	16	55	61	83
	A	19	19	11	21	16	16	18
vibrations bearing n° 4 "µm"	V	80	70	67	14	64	58	92
	H	50	50	54	25	53	45	43
	A	22	19	24	26	21	23	19

Table n°5: vibration levels on different bearings of the pump B unit n°2



Graph n°6: Evolution of vibration on bearing n° 3 of the pump B unit n°2



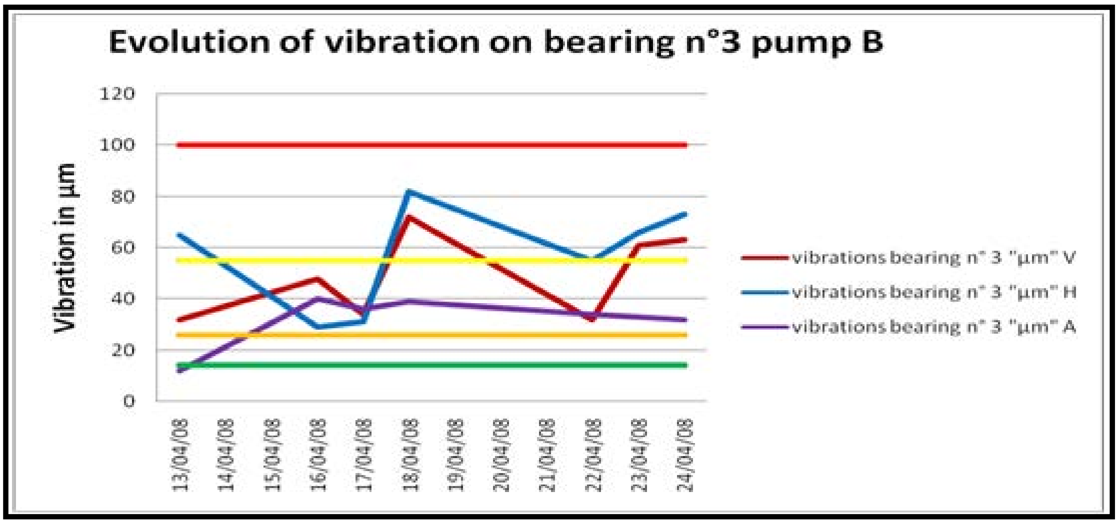
Graph n°7: Evolution of vibration on bearing n°4 of the pump B unit n°2

3. *Incidents in 2008:*

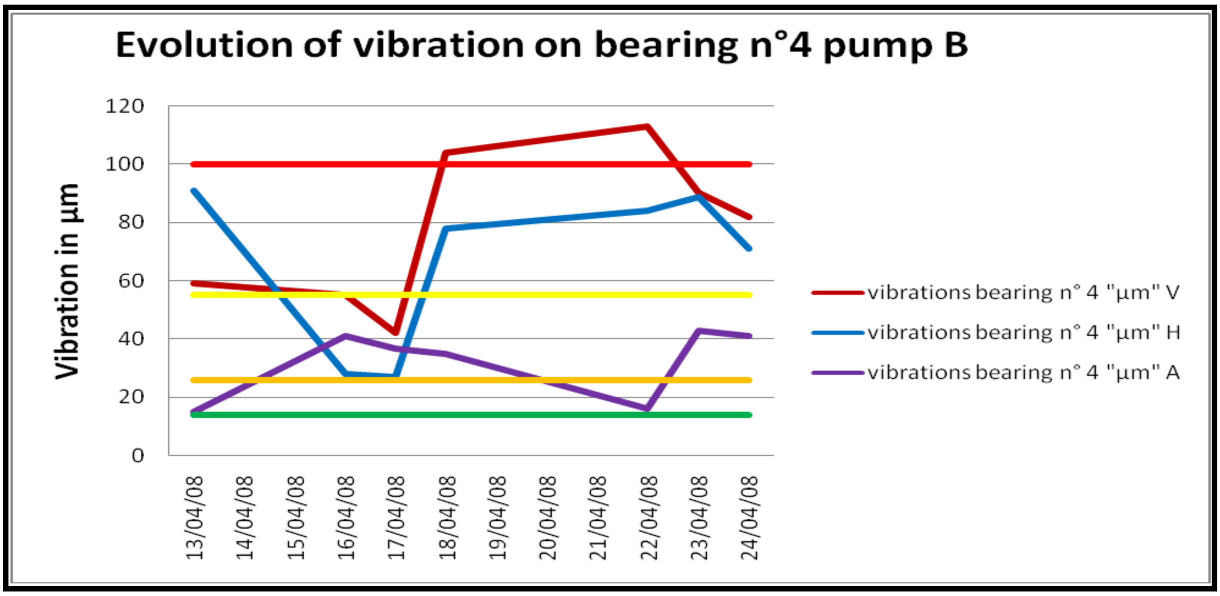
Evaluation of vibrations of the pump B n°1

Date		13/04/08	16/04/08	17/04/08	18/04/08	22/04/08	23/04/08	24/04/08
vibrations bearing n° 1 "µm"	V	37	8	10	17	16	27	25
	H	23	10	9	19	13	12	13
	A	30	35	37	30	21	17	16
vibrations bearing n° 2 "µm"	V	22	46	42	45	37	40	38
	H	10	14	20	18	20	25	27
	A	9	21	23	27	14	21	21
vibrations bearing n° 3 "µm"	V	32	48	34	72	32	61	63
	H	65	29	31	82	55	66	73
	A	12	40	36	39	34	33	32
vibrations bearing n° 4 "µm"	V	59	55	42	104	113	90	82
	H	91	28	27	78	84	89	71
	A	15	41	37	35	16	43	41

Table n°6: vibration levels on different bearings of the pump B unit n°1



Graph n°8: Evolution of vibration on bearing n° 3 of the pump B unit n°1



Graph n°9: Evolution of vibration on bearing n°4 of the pump B unit n°1

According to these graphs, we have registered severe vibration (26 at 55µm) at very severe vibration (> 100 µm) on bearing n°3 (horizontally) and bearing n°4 (vertically) (the bearings n°3 & 4 are the bearings of the pump). At vibration level to 60 through 80µm, the alimentary pump start to breakdown as a result of wear. In fact, the first consequence of vibrations is manifested in the bearings which begin to wear down. As the vibration level increase, so the wear is transmitted to other organs of the pump as the sealing rings which ensure the watertightness between the different chambers. Indeed, their wear causes leaks between the different chambers and generated then an axial displacement of the shaft which is manifested in the disc of balance which is none other than an image of the displacement of the shaft. Therefore, this latter one accelerates the rate of wear by the friction and so it risks the shear of the shaft.

The following pictures illustrate the measuring points on which the vibration levels were recorded.

Figure n°5: bearing n°1 motor side

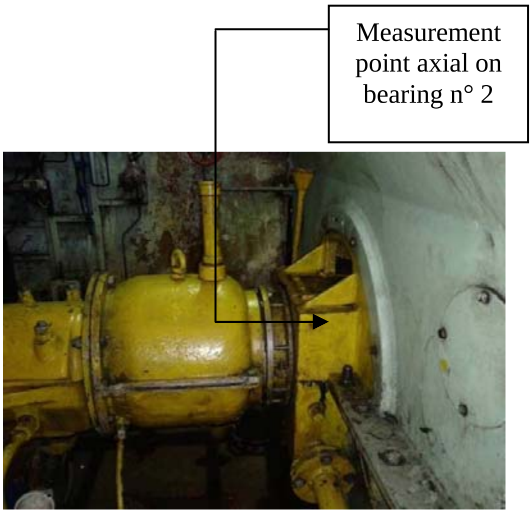


Figure n°6: bearing n° 2 motor side

Figure n°7: bearing n°3 pump side

Measurement point horizontally on bearing n° 3

Figure n°8: bearing n° 4 pump side

Measurement point vertically on bearing n° 4

It should be mentioned that the investigations of vibration levels on the bearings of the alimentary pumps are irregular. These investigations give no idea of the causes of these vibrations.

V. THE DEFECTS OF THE ALIMENTARY PUMPS:

There is no predictive maintenance without a minimum diagnosis of the defects and their severity. For this reason, the first step of a monitoring action is to ask what the potential defects of the monitored machine are. The second concern the manifestation of these defects. What information, what descriptor parameters of the defect must be elaborated up and be measured to require solid information; that will allow us to tell if the situation is normal or not (detecting abnormality), but also to those that which allow to found subsequently their origin (diagnosis of the origin and the severity of abnormalities) [5].

First, we will explain the different problems that can arise in the alimentary pump.

A. Unbalance (or balancing defect) :

An unbalance is a state of «no concentricity » of the centres of gravity of rotor components. In fact, a rotor usually consists of an assembly of many moving parts. If the gravity center of these elements do not coincide, we have what we call unbalance [6].

B. Misalignment :

The motor shaft and the machine shaft are not perfectly aligned [7].

1) Angular misalignment :

The angular misalignment happens when axis of the shafts intersect. The vibration is radial and axial. A curved shaft behaves in a similar way.

2) Parallel misalignment :

When the centerlines of shafts are assembled in parallel that never meet, we have a parallel misalignment.

3) Combined misalignment :

In industrial applications, the misalignment will be combined: both, parallel and angular. Also the two criteria of severity will be combined.

C. Bad tightening :

When a bearing is loosened or has a possibility of partial movement in the radial plane, a radial mode of vibration appears at a frequency equal to twice of the rotation speed. This vibration is produced by initial unbalance and can take up high amplitude according to the degree loosening of bearing [1].

D. Electrical defects :

The vibrations of the metal parts of the rotor and the stator under excitation of electromagnetic fields produce peaks at frequencies equal to those of the sector and to its harmonics. An increase of these peaks may be a sign of the degradation of the motor (for example gap variation) [1].

E. oil whirl:

This phenomenon appears on the weakly loaded smooth bearings slightly polluted lubricated in the hydrodynamic regime. It occurs slightly below half the frequency of rotation of the shaft (from 0.42 to 0.48 times the frequency rotation according to the bearing characteristics). This along imbalance of the rotor and a resonance frequency nearly the rotation speed, led to the whipping phenomena of rotor [1].

VI. DEVELOPMENT OF A VIBRATION MONITORING SYSTEM OF ALIMENTARY PUMPS:

The monitoring method described above which consists of an irregular campaigns of investigations of vibration levels of the alimentary pumps have been unable to avoid the huge losses experienced in 2005, 2006 and 2008. Following these incidents, several measures and actions were adopted to avoid similar unavailabilities in the future of these pumps, in particular:

- Establishment of monthly investigations vibration levels;
- Implementation of periodic revisions of the alimentary pumps;
- Development of a vibration monitoring system of these alimentary pumps.

This new maintenance policy will be based on the spectral analysis method instead of the global method.

The conditional maintenance platform include especially for each pump:

- Ten (10) vibration sensors (accelerometers with Frequency range: 0,8 to 12000 Hz) will be mounted on each pump as illustrated below and in the figure n°13:
  - V1-H, V1-V: on the bearing of the motor, fan side, horizontal and vertical directions
  - V2-H, V2-V: on the bearing of the motor, coupling side, horizontal and vertical directions
  - V2-Axial: on the bearing of the motor, coupling side, Axial direction
  - V3-H, V3-V: on the bearing of the pump, coupling side, horizontal and vertical directions
  - V4-H, V4-V: on the bearing of the pump, coupling opposite side, horizontal and vertical directions
  - V4-Axial: on the bearing of the pump, coupling opposite side, axial direction.

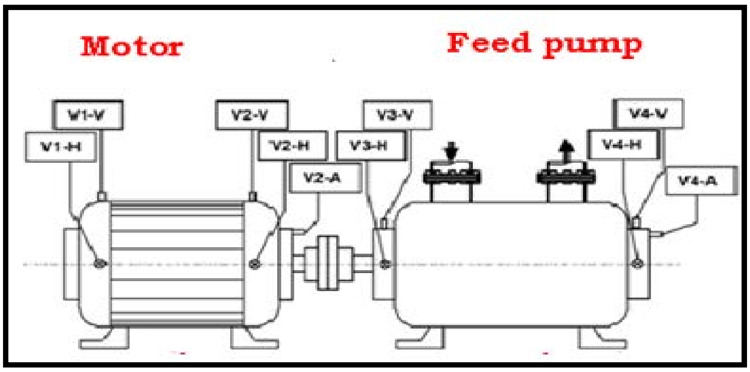


Figure n°9: Position of sensors on the pump

- One acquisition unit able to acquire at the same time several analog channels in the range 0-20kHz. It allows also to carried over collected data to the monitoring station in the control room and to generate the alarms according to alert levels.
- One Memo graph M with the following characteristics:
  - Type of display: graphical color display
  - Graphic data manager RSG40
  - Function: Memorization, visualization, analysis and communication
  - Electronic registration, display, representation, exploitation, remote transmission and archiving of analog and digital input signals.
  - Input number: 20
  - Output relay : 3 outputs
  - Memory SD external card slot and USB key
  - Supply : 230V AC
- Vibration Analysis Software with the following functions:
  - Archiving of vibration data and process (trends of monitored parameters),
  - Archiving of spectrum, envelops, zooms, times, kurtosis,
  - Graphical exploitation of results that allows to establish a diagnosis of the of the machines (trends, spectrums, envelop, times, kurtosis, orbits…)

- Automatic electrical diagnostis.

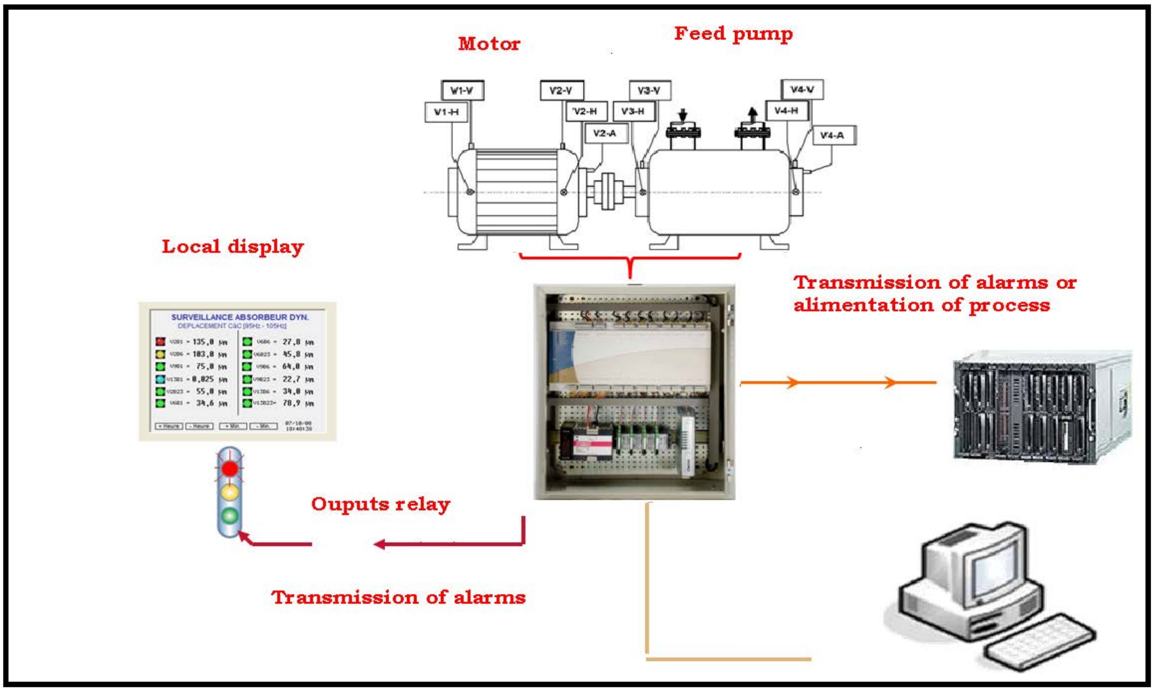


Figure n°10: Schema of vibration monitoring system oh the pump

The objective of this on-line monitoring method is not only to check that the eligible criteria or the alarm limits are not being reached, the analysis must indicate any abnormal evolution even if this is still under of the limits required by the instructions. It permits thus:

- To alert the operator by an early detection of degradations to avoid extensive damages of pumps;
- To help optimize the maintenance of these pump;
- To enhance knowledge of the attitudes of pumps and to help to the understanding of degradation processes, by an analysis of the monitoring data, of the diagnoses executed and their consolidation in an experience feedback. It contributes to the improvement of the safety and the unavailability and to reduce maintenance cost [2].

VII. CONCLUSIONS

The alimentary pump is the beating heart for a thermal power plant because it feeds continually the boiler by treated water which it is necessary to produce the superheated steam.

In our study site, this costly and strategic installation in the electricity production process have experienced several unavailabilities significant production losses due to a failing maintenance policy which had restricted to irregulars campaigns of investigations and the comparison of the vibration levels on the different bearings of this pump with reference values which are the danger and alert thresholds.

The very expensive losses of production because of the unavailability of this pump were the justifying basis of the transition to another conditional maintenance politics and predictive on this installation that consists to a vibratory monitoring to monitor the health of the pump in operation and to identify possible dysfunctions and their evolutions thus in order to plan in appropriate time the corrective actions.

The expected profits by the implementation of this monitoring policy are of two types:

- Minimization of incidents costs (repairs, downtimes) by an early detection of abnormalities;
- Minimization of maintenance costs;
- Fiabilisation and increase of the rate of availability of these pumps;
- Effective management for the stock of spare parts.

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