Improved Diagnosis of Boiler Feed Pumps in a Thermal Power Plant

R.Zarrouk, M. El Amrani, H. El Maati, H. Santillan-Ortiz

Abstract: ***In thermal power plants, the boiler feed pumps are classified as vital machines. Therefore, the lack of its availability leads immediately to a loss of electricity production. They can also be the source of serious incidents or accidents that directly threaten the operational safety of the machine, as well as the safety of personnel. The inspection is a very effective solution to reduce the possibility of an accident. The vibration analysis can specifically detect with opportunity the possible mechanical, hydraulic and electrical defects that probably exist in motor pump. This document presents different techniques of vibration analysis, which were applied in different pumps to make an effective diagnosis.***

Keywords ***: Control and diagnosis of motor pumps, spectral analysis, envelope analysis, time-frequency analysis, scalogram.***

I. INTRODUCTION

To satisfy the growing consumption of electricity, it is necessary to guarantee its production efficiently and continuously. In order to achieve this objective, the strategic facilities of the production units have to be reliable and must be maintained in optimum conditions, In particular the turbo units and the feed pumps that constitute the main facilities of the thermal power plant.

The maintenance of these strategic facilities has the following objectives: firstly the security, which guarantees the safe operation of machinery and the integrity of people. Secondly the economic factor, which limits untimely downtime. It should be borne in mind that the Jerrada power plant in Morocco, despite the redundancy of the pumps, has caused large losses in production in the last ten years, synonymous with a loss of several thousand dollars in revenue [1-3].

Of all the techniques of conditional maintenance, the vibration analysis is the most appropriate technique for rotary machines [4-7]. Not only it informs about the state of the machine health, but also it can detect the defective part and even the type of defect. In fact, the vibratory signals generated by these machines contain valuable information about their correct operation. The processing of these signals can provide an accurate diagnosis of the machines. Several analysis techniques depend on the used type of signal processing [8]. These treatments are often complementary and necessary for a good diagnosis. Three types of analysis were applied to our boiler feed pumps: frequency analysis, envelope analysis and time-frequency analysis.

II. TECHNIQUES OF ROTATING MACHINES VIBRATORY ANALYSIS

The vibration analysis is based on the evaluation of the measured vibratory signal with the help of an accelerometer placed near the organ to be monitored. There is a multitude of time, frequency and frequency methods. These methods are complementary for a better diagnosis. In this paragraph we mentioned the principle of the most common methods used to control boiler feed pumps.

- Spectral analysis [8] whose principle is to measure the time signal x (t), and then calculate its spectrum X (F). This calculation can be done using the Fourier transform; but since vibratory signals are generally random, it is preferable to use the Spectral Power Density (SPD) representing the Fourier transform of the autocorrelation of the measured signal x (t)[9], that is :

$$SPD(F)=|FT\ (Rx(t))| \quad (1)$$

  Where FT is the Transform Fourier and Rx (t) the autocorrelation of the signal x (t), defined by equation (2):

$$Rx(t)=\lim_{T\to\infty}\int_{-\infty}^{\infty} x(t).x(t+\tau)\ dx \quad (2)$$

  Knowing that most of the anomalies affecting the rotating machines (imbalance, misalignment, fixation, and electromagnetic defects) generate to vibrations whose frequencies correspond to the appearance frequencies of the forces which induce these anomalies; the comparison of the measured spectrum with the spectral signatures of these defects reveals their presence.
- Phase analysis [8] is a technique complementary to spectral analysis. It allows to separate the defects resulting from the rotation forces from those coming from the directional forces. The principle consists of simultaneously measuring two signals using two sensors placed perpendicularly on the same level.

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Then, we calculate the frequency signal of each measurement, and we deduced the phase shift at the rotation frequency of the shaft. If this phase shift is close to 90 °, so the defect is linked to a rotation force. If it is close to 0 ° or 180 °, then the defect is related to a directional effort.

It is a widely used technique to separate the imbalance defect from the fixation fault that has the same spectral signature.

- Envelope analysis is a technique that highlights bearing failures [10-11], gear failures [12] and electric motors failures [13-14].

Although this modulation produces, in the spectrum, lateral bands around the main frequencies of the system (meshing frequency, notch frequency, etc.). These bands are very little visible due to their low energies; it requires amplitude demodulation to highlight them.

The envelope analysis, consists to measure the filtered time signal x (t) around the carrier Fp (the carrier Fp is the notch frequency in the case of electric motors the meshing frequency in the case of the gears and the resonance frequency in the case of bearings), and then to calculate the relative analytical signal z(t) at the filtered signal x (t), it should be referred to as Equation 3:

$$z(t)=X(t)+(X(t)*\frac{j}{\pi t}) \quad (3)$$

By definition $x(t)*\frac{1}{\pi t}$ is the Hilbert Transform (HT) of x (t). Equation (3) can be rewritten as :

$$z(t)=X(t)-j*HT(X(t)) \quad (4)$$

The envelope e (t) of the signal x (t) is defined by the module of the analytic signal z (t):

$$\boldsymbol{e}(t)=|z(t)|=\sqrt{X^2(t)+HT^2(X(t))} \quad (\mathbf{5})$$

The spectrum of the envelope would contain modulation lines whose position reveals the type of defect that gives rise to this modulation.

- The Time-frequency analysis is an analysis that allows to characterize the frequency content of a signal as a function of time. Several types of time frequency representations are proposed [15], but it is the wavelet transform that gives the best results [16-17].This transformation consists in decomposing the signal that will be studied based on elementary functions called wavelets $\psi_{a,b}(t) = \psi\left(\frac{t-b}{a}\right)$, time function b and frequency 1/a. The coefficients C (a, b), obtained by decomposing the signal x (t) in the family $\psi_{a,b}(t)$, are given by Equation (6):

$$C(a,b) = \frac{1}{\sqrt{|a|}}\int_R x(t)\psi_{a,b}(t)dt \quad (6)$$

The choice of mother wavelet depends, among others, on the type of the signal to study and the field of application. In this study, we chosed the Morlet wavelet [18], defined by Equation (7):

$$\psi(t) = e^{-j\pi n\frac{t}{T}}\, e^{\frac{-t^2}{2T^2}} \quad (7)$$

Where T is the duration of the signal x (t) and n is the product of the center frequency Fo by T, then $n = F_0.T.$ From this decomposition, we have created the Scalogram Scal (a, b) defined as the square of the wavelet transform C (a, b), that

Is:

$$Scal(a,b)=|C(a,b)|^2 \quad (8)$$

The scalogram, defined by the "Equation (8)", is used in vibrational analysis to highlight amplitude modulation and frequency modulation [19].

In effect, the amplitude modulation is reflected in the scalogram by the appearance of a series of energy "blocks" equidistant and parallel to the time axis; while the frequency modulation gives rise to blocks distributed non-linearly according to the time axis and the frequency axis.

III. DESCRIPTION OF THE BOILER FEED PUMP

The motor pump unit of our thermal power plant consists of (Fig. 1 and Fig. 2):

- A synchronous electric motor of type ATD 2000 that rotates at a frequency of rotation Fr = 50 Hz. The number of notches of the rotor is 38, which gives a notch frequency F_n = 1900 Hz.
- Tow Fans installed on the motor shaft; its role is to provide sufficient cooling air. The number of blades for each fan is 8 which gives pass frequency of blades: F_b = 400Hz.
- A rigid coupling that connects the electric motor to the pump.
- A barrel-type pump coupled to the electric motor. It is a centrifugal, multicellular and horizontal pump, ten stages and operates at a speed of 3000rpm, a rotation frequency of 50Hz. Each stage contains 9 blades, that is, a blade frequency F_a = 450 Hz.
  - A lubrication pump at the end of the shaft.

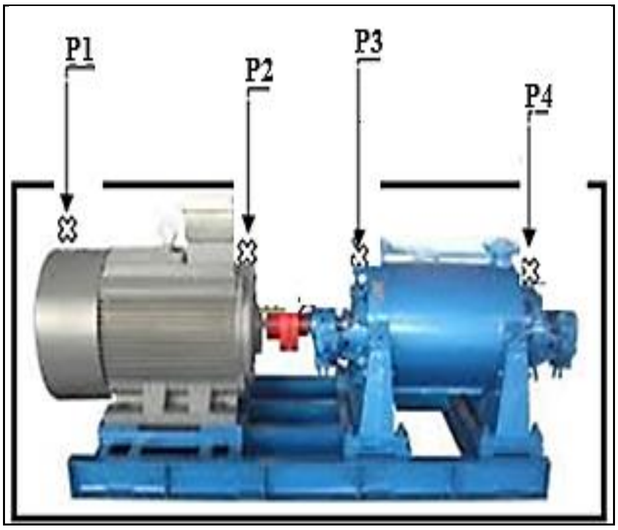

Fig. 1. Boiler feed pump diagram

Fig. 2. Photo of Boiler feed pump Thermal Power plant

IV. VIBRATION ANALYSIS OF THE BOILER FEED PUMP

Four measuring points were chosen for the control of the boiler feed pump: P1, P2, P3 and P4. In each of these points, a global analysis was taken. Measured RMS levels indicated that the pump was in poor condition.

Subsequently, frequency analysis, envelope analysis, frequency analysis and time for diagnosis were applied.

At point P1, the signals in the horizontal radial, vertical radial and axial directions in the frequency band [0-2.5KHz] were measured with a line number NL = 800 to verify the faults occurring at low and frequencies stockings such as imbalance, play, friction, shaft curvature, motor fixing, fan failures, etc.

Envelope detection was also performed around the notch frequency of the Fn = 1900Hz motor to control:

- Stator faults [8] such as centering fault, ovalization of the stator body, winding fault, phase imbalance, turns or leaves that are shorted or loose.
- Rotor faults [8] stories such as eccentricity of dynamic space, broken or cracked bars, leaves or shorted.

At point P2, the same measurements were taken as at point P1 to control the same defects mentioned above in addition to the misalignment between motor and pump.

At point P3**,** the signals in the horizontal radial, vertical radial and axial directions in the frequency band [0-2KHz] were measured with a line number NL = 800 to verify the faults related to the pump and to the coupling.

At point P4, the same measurements were taken as at point P3 to verify the same defects as well as the misalignment between the main pump and the lubrication pump.

V. RESULT AND DISCUSSION

During the control of the boiler feed pump, the acquisition of the signals was carried out by the Vibxpert system while the **software V_System** [20] ensured visualization and signal processing.

At point P2, the spectrum measured in the horizontal radial direction is visualized in Fig. 3.

The 50 Hz, 100Hz, 150Hz and 200Hz lines have a large amplitude among the probable defects are imbalance and fixation. To eliminate this indeterminacy, a phase analysis was carried out. The phase shift measured at the rotation frequency is about 90 °, which shows the existence of an imbalance.

The 100 Hz line is preponderant: the faults generated by this line are the parallel misalignment or variation of the stator current gap. For an exact determination of the defect, the frequency of the Fn = 1900Hz slot was extended (Fig. 4).

The small lines are present around the notch frequency that indicate the presence of the modulation phenomenon.

An envelope detection around Fe was then carried out.

The spectrum of the obtained envelope is visualized in Fig. 5, in which a dominant line at 100 Hz and a line at 50 Hz are seen, indicating the presence of a stator defect and a rotor defect of the dynamic space eccentricity type.

Since the amplitude of the 100 Hz line is much greater than that of the 50 Hz line, the stator defect is therefore more advanced than the rotor defect.

It should also be taken into account that in Figure4, the peak at 1850 Hz is greater than the peak at 1950 Hz, so the band on the left side is larger than the right and consequently frequency modulation induced the modulation of the amplitude.

To highlight this frequency modulation it was calculated to then represent the scalogram of the signal measured in P2, in Fig. 6.

The shape of the scalogram shows the presence of a frequency modulation. The modulation frequency is equal to 50 Hz, it is likely to be a crack in the rotor shaft.

At point P4, the spectrum measured in the horizontal radial direction is shown in Fig. 7. The occurrence of a resonance located after the frequency of 100 Hz is observed, that is, twice the rotation frequency of the axis; and other resonances located after the frequency of passage of the vanes of the pump F_a = 450 Hz and their harmonics. This is the spectral signature of a cavitation defect [21].

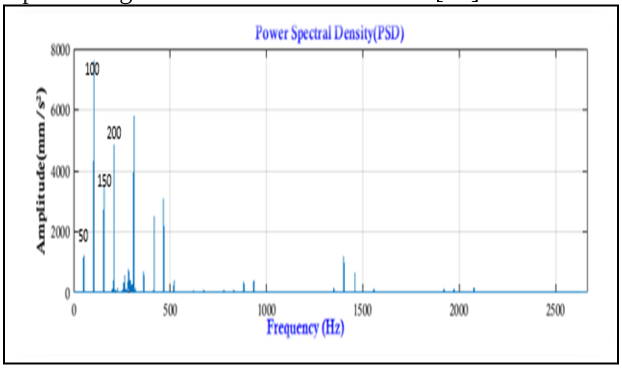

Fig. 3. Spectrum measured, at point P2, in the horizontal radial direction

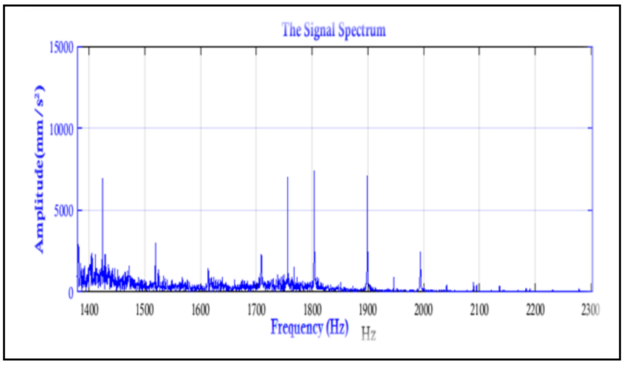

Fig. 4. Spectrum zoomed around Fn = 1900Hz.

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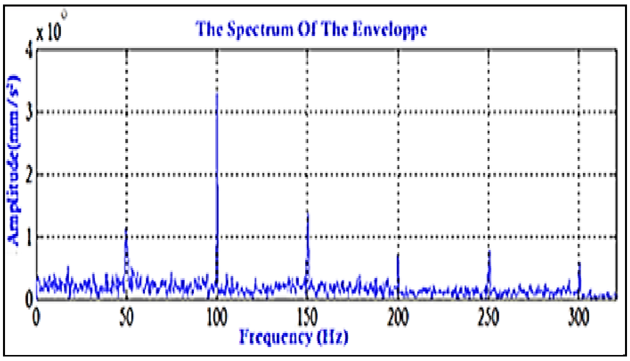

Fig. 5. Spectrum of the envelope measured a round Fn = 1900Hz.

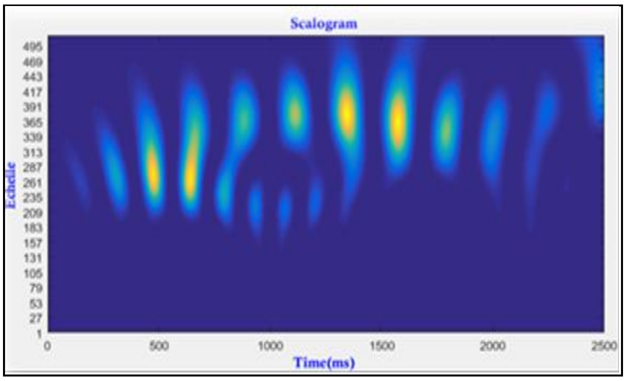

Fig. 6. Scallogram of the signal measured at point P2, in the Horizontal radial direction

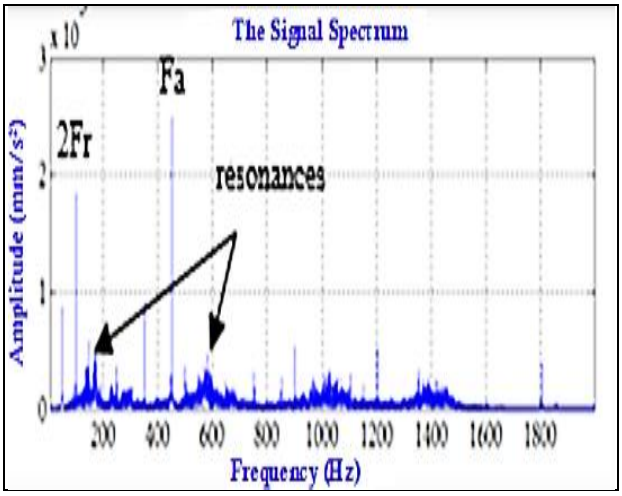

Fig. 7. Spectrum measured, at point P4, in the horizontal radial direction.

VI. CONCLUSION

The boiler feed pump represents, for the thermal energy plant, the "heart" that beats since it continuously supplies the boiler with the treated water necessary for the production of superheated steam that turns the turbine. Its continuous inspection is therefore necessary.

Vibration analysis is a very effective conditional maintenance technique for the control and diagnosis of rotating machines.

The application of the spectral analysis and the phase analysis to the controlled motor pump revealed the existence of an imbalance in the motor shaft and the existence of a cavitation defect in the pump. In the same way, the analysis of the envelope has shown the existence of a defect in the stator and a dynamic defect of the eccentricity of the rotor.

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