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# STRUCTURAL DIAGNOSIS OF A HYDRAULIC TURBINE GENERATOR USING PERIODICAL VIBRATION SIGNAL ANALYSIS

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SUMMARY: In many practical cases of machinery noise and vibration analysis it is necessary to detect the periodical components, which are correlated with different dynamical effect occurring in the working time, in fault detection important being the accuracy of magnitudes and phases of harmonic components. Using the classical FFT analysis of the signal, even without noise components presented, the harmonic components required can be affected by large errors even using Zoom analysis. The paper presents an algorithm which the harmonic components are identified by the spectral lines. The algorithm was successful verified on the structural diagnosis of a hydraulic turbine generator using periodical vibration signal analysis.

## 1. INTRODUCTION

Harmonic analysis can be performed analogical using the tracking filters or by digital process. Although the digital analysis of FFT spectrum seems to be a high accurate method, large errors of harmonic components estimation can occur, even by using the Zoom digital facility.

The paper presents an algorithm for harmonic components detection which is identified by spectral lines of one ordinary FFT spectrum. The high accuracy of harmonic component parameter estimation (amplitude and frequency) is demonstrated applying the algorithm for analysis to one group of vibration signal simultaneously recorded by transducers placed on the stator of an electric generator of a 175 Mw hydraulic turbine [2].

## 2. HARMONIC COMPONENT DETECTION ALGORITHM

The Fourier integral components, Re(ω) real and Im(ω) imaginary, for a time finite record length T of one signal u(t) are of the form:

$$\mathrm{Re}(\omega)=\frac{2}{T}\int_0^T u(t)\cos(\omega t)dt;\quad \mathrm{Im}(\omega)=\frac{2}{T}\int_0^T u(t)\sin(\omega t)dt \tag{1}$$

where ω is the angular frequency argument.

Applying the two forms to a harmonic signal:

$$u(t)=X\cos(\omega_h t)+Y\sin(\omega_h t) \tag{2}$$

if the signal u(t) record length T is given by N samples having the sampling time interval Δt, then the equations (1) are transformed in the discrete forms:

$$\mathrm{Re}(i)=\frac{h+k}{\pi\left((h+k)^2-i^2\right)}\left(X\sin 2\pi k-Y(\cos 2\pi k-1)\right) \tag{3}$$

$$\mathrm{Im}(i)=\frac{i}{\pi\left((h+k)^2-i^2\right)}\left(X(\cos 2\pi k-1)+Y\sin 2\pi k\right) \tag{4}$$

where Re(i) and Im(i) are the real and imaginary components to $i^{th}$ spectral line, of frequency $\omega_i=i\Delta\omega$, and $\Delta\omega=2\pi/T$ being the spectrum frequency increment.

If an harmonic component of frequency $\omega_h$ exists, it has to be located in the spectrum close to a peak line, of frequency $\omega_p$, as well as the $h^{th}$, the two, $\omega_h$ and, $\omega_p$ having the forms:

$$\omega_h = (h+k)\Delta\omega; \quad \omega_p = h\Delta\omega \tag{5}$$

k being a fractional number, -1<k<1.

For k=0, $\omega_h=\omega_p$, and the harmonic component occurs identical with the peak line in spectrum, all other spectral side band lines having their magnitudes nulls.

If $k\neq0$, then the energy of the harmonic component is spread over its frequency side bands so that the estimation of both, Re(i=h) and Im(i=h) lead to significant errors.

Taking into account the fact that $h>>|k|$, and for s= -1,0,1 the spectral amplitudes U(i), in the close band of the peak line, occurring, from (3) and (4), are of the form:

$$U(i) = \sqrt{Re^2(i) + Im^2(i)} \approx U_h \left| \frac{\sin(\pi k)}{\pi(k-i+h)} \right| , \tag{6}$$

where

$$U_h = \sqrt{X^2 + Y^2} \tag{7}$$

is the true amplitude of harmonic component, which need to be identified.
It is demonstrate that the error function reach the maximum value of 36.3% at k=0.5 and s=0, unacceptable even for a ordinary vibration signal analysis [1].

The estimation of harmonical components need to be identification the fractional number by the equations (3) and (4) using the more then 3 spectral line around a peak which hidden a harmonic component.

## 3. APPLICATION TO VIBRATION DIAGNOSYS OF AN HYDRAULIC TURBINE STATOR

### .3.1. Stator vibration excitation

A Kaplan hydraulic turbine, of low speed, is one of the largest dimension power machines. For a 178 MW turbine (Figure 1), as of the Iron Gate 1 Power Station turbines (on Rumanian side of Danube), the stator frame 1 is of 17m supporting in its slots 18 windings coils 2 consisting from isolation copper bars In-slot bar vibration respond primarily as electromagnetic forces and thermal cycling. [3].

Under normal conditions, a sure fasten of coils in the slots, the vibration measured on the stator frame, are of low level, and consisting from a single main harmonically component of 100 Hz, because the electromagnetic forces acting on coil structure are of approximate form

$$F_c(t) = k_m U_0^2 \sin^2(2\pi f t) = \frac{1}{2} k_m U_0^2 (1 - \cos(2\pi(2f)t)) \tag{8}$$

where $k_m$ is a constant, $U_0$ amplitude of the coil excitation voltage of frequency f=50 Hz.

As material ages, shrinks and settles in, slackness develops within the slots, allowing the coils 2 to increasing vibrate. The coils 2 are fasten in the stator frame slots by the pins 4, which under mechanical and thermal stress loses, during working time, the adherence between, even clearance occurring. As results the vibration of the coils and stator frame become more intensive and multicomponents periodically and randomly.

Thus, the multicomponents vibration is both symptom and cause of: bad wedging of the bars and blocking/bracing of end-winding, operation condition (mechanical stress, electrical stress and thermal cycling), fatigue of end winding, moinsture contamination, abrasion and reduction of isolation.

Vibration is direct and indirect cause of: fatigue of mechanical components of stator, loss of ground contact between bars and stator core, insulation cracking, delamination, reduced electrical and mechanical strength of insulation discharge (slots, end-winding) and many others.

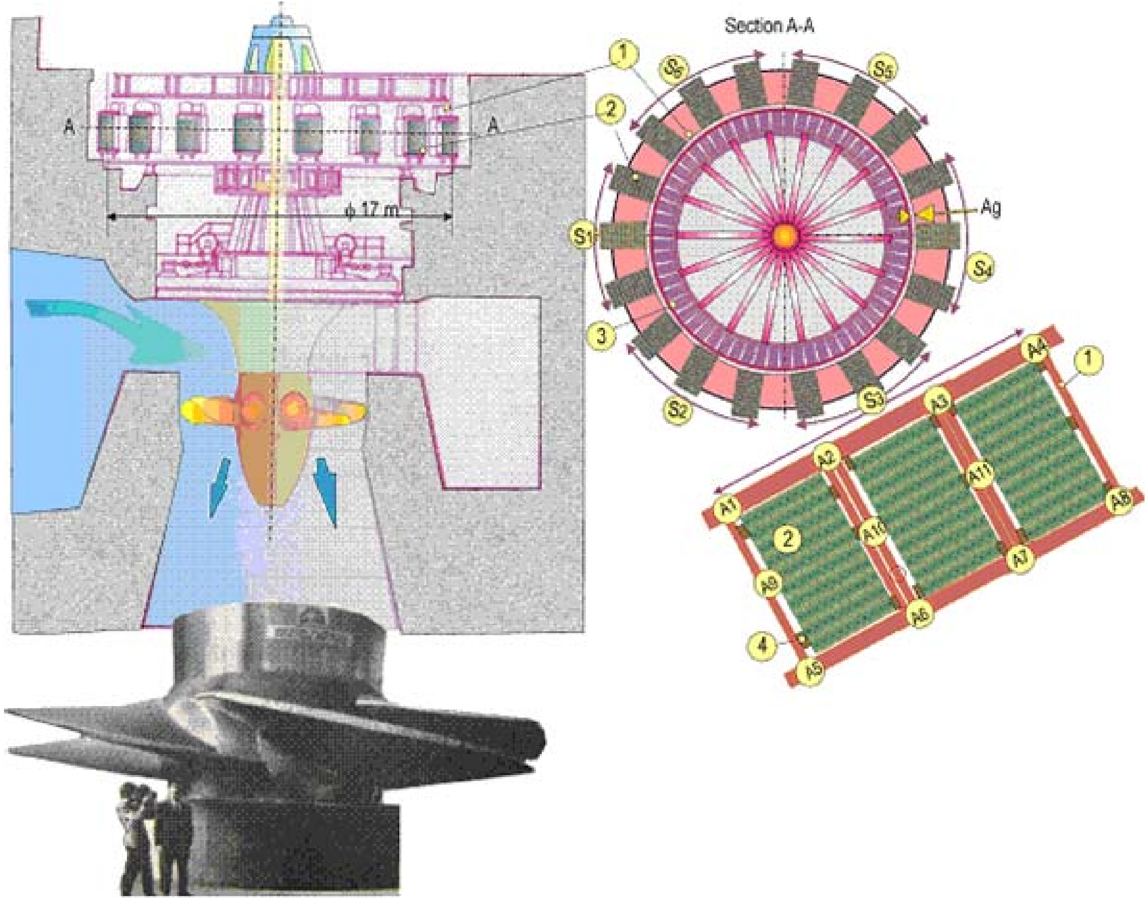

*Figure 1. A 178 MW hydraulic Kaplan turbine components and accelerometer setups for stator vibration measurement.*

### 3.2. Experimental measurements and results

For first information about the vibration components of stator structure it was performed measurement vibration along the stator structure the signals being analyzed using the above presented algorithm.

In figure 2 are plotted two string of the spectrums of 11 signals of the accelerometers $A_1,\ldots,$ $,A_{11,}$ (Figure1) placed on the stator frame 2, in the area of sector 3. The harmonics components of the signals, processed in velocity values, are printed directly on spectrogram ($v_{peak}$) together with the values of frequency f and phase $\psi$. The turbine generator was not connected to the power network (power delivered 0 MW), only excitation voltage being connected at three levels; 0, 4 and 8 kV, which are correlated with the levels of vibration, the highest level being, according to the form 10, for the last, 8 kV excitation voltage. Also, according to 10, the dominant components in the spectrums is that around of double network frequency of 100 Hz. Taking into account the fact that the signals of accelerometer where first recorded on tape, the signals being affected by flatter effect, it can be observed a accuracy frequency estimation by the paper algorithm, the increment in the FFT spectrum being relative large, of $\Delta f=\Delta\omega/2\pi$ =0.893 Hz.

High accuracy of harmonics component estimation is find out from spectrum plotted in Figure 2, where the turbine is loaded at 87 and 175 MW, where the output voltage frequency is tuned by electric network connected of 50 Hz.

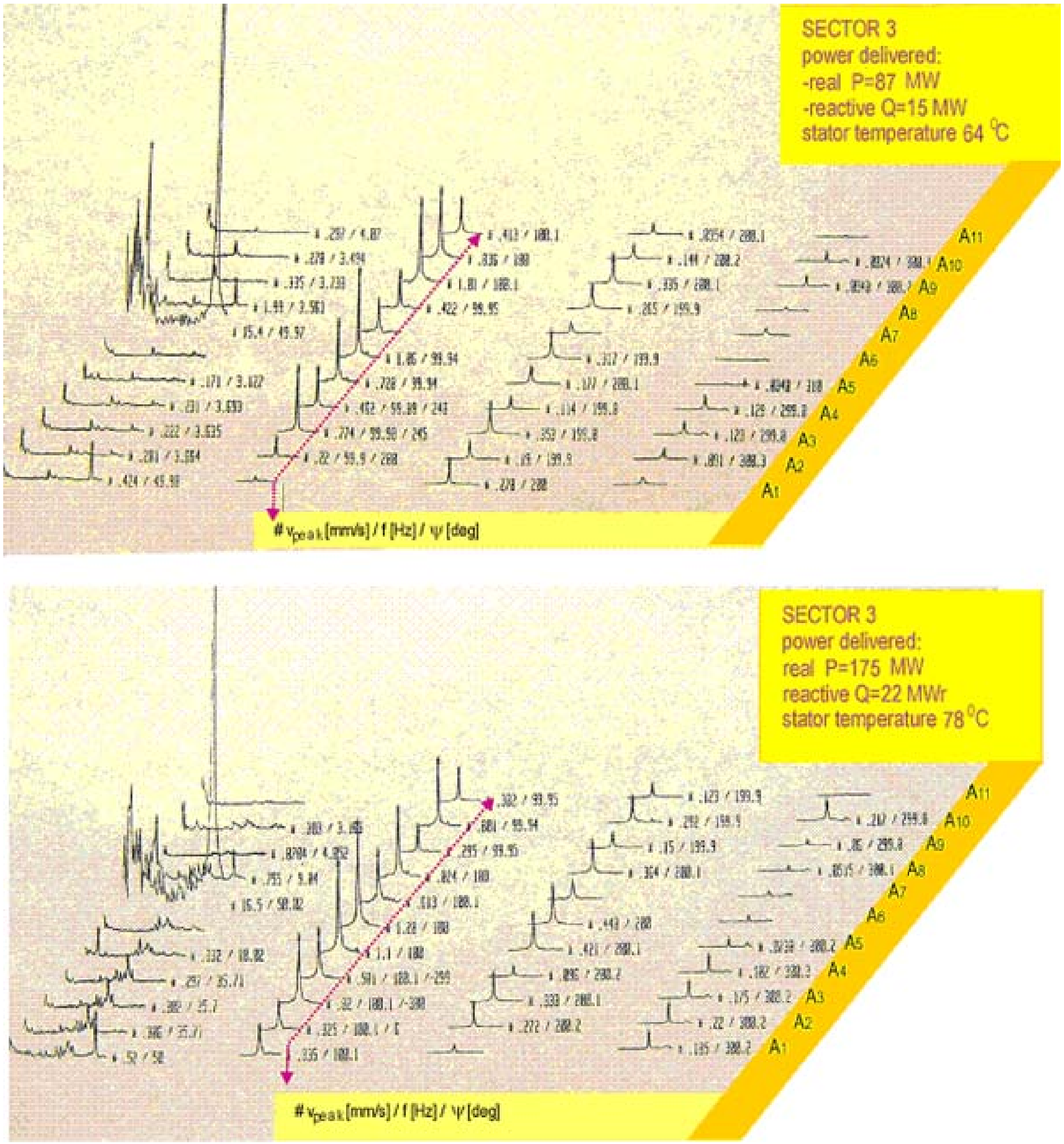

***Figure 2. Vibration spectrums of the 11 signals recorded by the accelerometers $A_{1,\ldots,}A_{11}$ (Figure 1) placed in Sector 3 of stator frame area.***
***Load of the turbine at 87 and 175 MW, delivered power.***

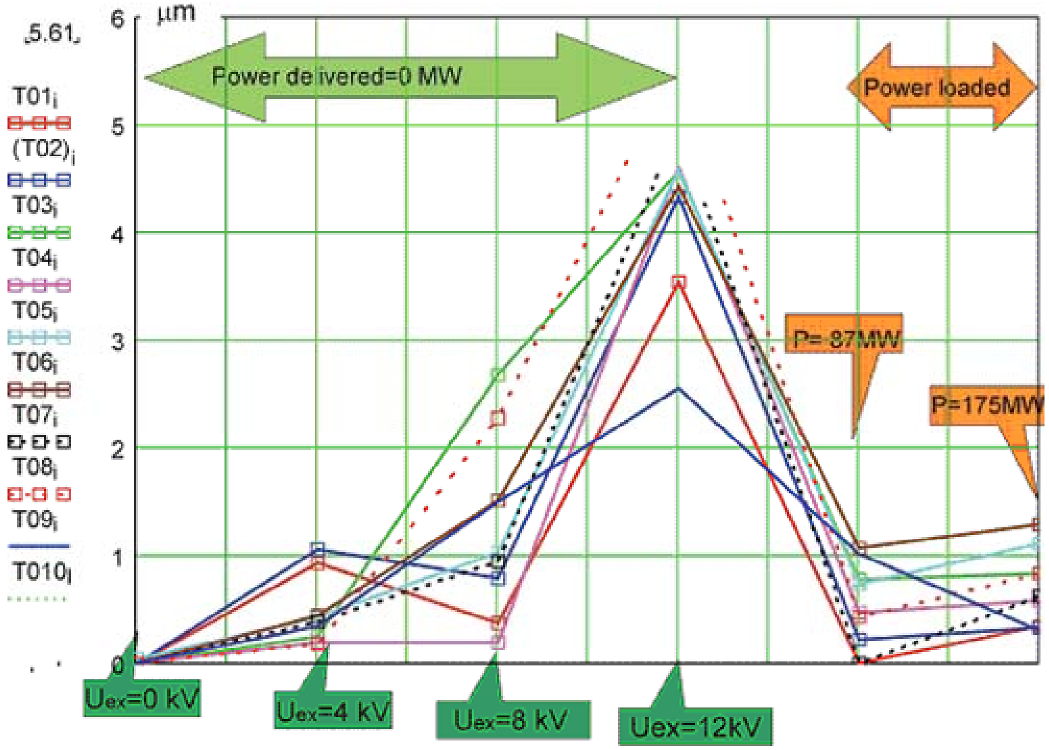

*Figure 3a. Illustration of the 2x (100 Hz) component vibration magnitudes for the 11 points of the generator stator.*

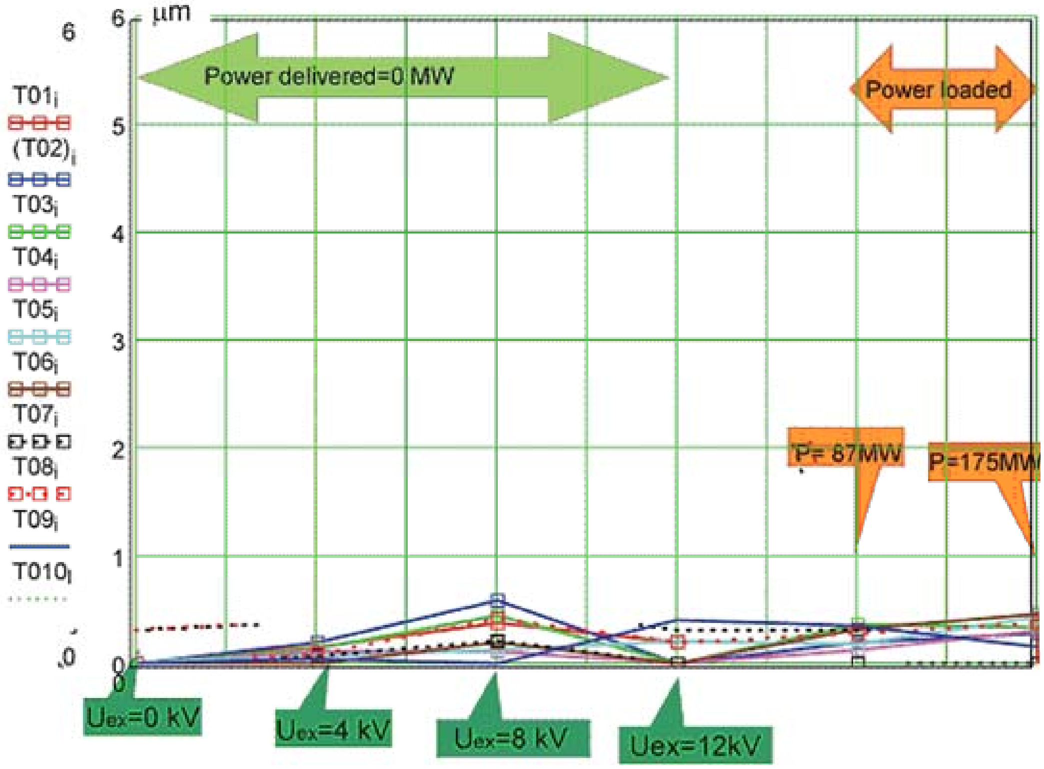

*Figure 3b. Illustration of the 4x (200 Hz) component vibration magnitudes for the 11 points of the generator stator.*

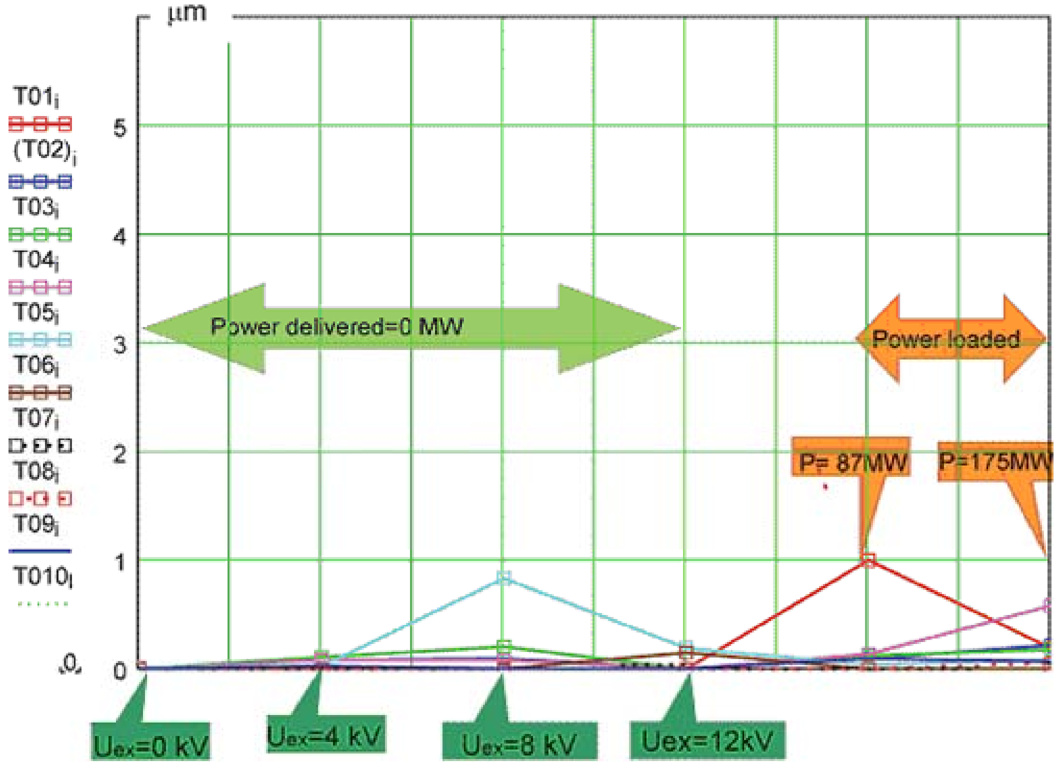

*Figure 3c. Illustration of the 6x (300 Hz) component vibration magnitudes for the 11 points of the generator stator.*

In view to have a comparative analysis between the all 11 signals recorded on the sector 3 in figures 3a, 3b, and 3c are plotted theirs magnitudes as function of turbine loads. First three strings of magnitudes correspond to the unloaded state, power P=0 MW and to three different excitation voltages Uex=0; 4; 8; and 12 kV and the last two corresponding to the loads of P=87 and 175 MW.

The maximum level of vibration correspond to the unpowered state and excitation voltage Uex=12 kV where the magnetic field is maximum, occurring the notable magnetic forces acting on coils and connected parts. For the case of the turbine generator is connected to power network at P=87 MW and the nominal power P=175 MW the magnitudes of components corresponding to 2x frequency (100 Hz) are more lower as in the unloaded generator (P=0), normally for interaction of magnetic forces between magnetic fields of stator and rotor.

During the continue working time, under variable forces, may appears unfastens between coil and connected parts which induce nonlinear effects, occurring, in this case of the periodical excitation (of 100 Hz) multiple (200, 300 ..Hz) and submultiple (0f 50Hz) periodical vibration motions. The combination of these components magnitudes are related with the unfasten ratio in the area of vibration measured by an accelerometer. In this aim the accuracy of the periodical component magnitudes estimation is strictly necessary, the methods and algorithm above presented and applied are very useful.

## 4. REFERENCES

[1] Căplescu, C., Hule, V., Cioara, T.,G., Periodical components extracting from a complex signal. Paper 1090, International Conference on Engineering Dynamics, Carvoeiro, Portugal, 2007;

[2] Cioara, T,G., Vibration in engineering CD Lectures. University “Politehnica” of Timişoara (in Rumanian);

[3] Vibration measurement on the stator ensemble turbine no.1, from Power Station “Iron Gate”, Rumanian side of Danube. Research Report no.34/02 of Vibration Testing and Research Laboratory, (VTRL) of University of Timişoara, (in Rumanian, unpublished).