APPLICATION OF FULL SPECTRUMS AND OTHER VIBRATION TWO-DIMENSIONAL CHARACTERISTICS FOR GAS TRANSPORTATION UNITS CONDITION MONITORING

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It is well known fact that the more independent symptoms are using when machinery condition has to be defined the better is the diagnosis ultimately. At the paper is shown that application of combined full spectrum [1, 2] and orbit analysis technique permits to recognize unit defects which are not recognizable enough with using only common spectrum features. This condition monitoring tool was pioneered by Bently Nevada Co. specialists [1, 3, 4, 5] and needs to be applied more widely in vibration analysis due to its usefulness. The full spectrums are good instruments to investigate separate frequency components not only on their amplitude values but on precession direction as well to provide important diagnostic information. So, elliptical orbit form of filtered around definite speed ω vibration components can be presented [5] as a sum of the circle orbits pair: the first one goes along the shaft rotation direction (forward) with radius of $\boldsymbol{R_\omega}^+$ and the second one - in opposite direction (reverse) with radius of $\boldsymbol{R_\omega}^-$, and these are just the full spectrum components in consideration. The mathematical equations for full spectrum components calculation are as follows:

amplitude of forward precession at the circular frequency $\boldsymbol{\omega}$

$$R_\omega^+ = [X_\omega^2 + Y_\omega^2 + 2X_\omega Y_\omega Sin(\alpha_\omega - \beta_\omega)]^{1/2}; \quad (1)$$

amplitude of reverse precession at the circular frequency $-\boldsymbol{\omega}$

$$R_\omega^- = [X_\omega^2 + Y_\omega^2 - 2X_\omega Y_\omega Sin(\alpha_\omega - \beta_\omega)]^{1/2}, \quad (2)$$

where X_ω, α_ω and Y_ω, β_ω are ω-frequency components (amplitude and phase) of Fast Furie Transformation (FFT) of Horizontal X and Vertical Y relative vibrations respectively. Then precession direction ("forward"- as shaft rotate, or opposite one – called "reverse") is easily defined by predominating spectral line from the pair $\boldsymbol{R_\omega}^+$ and $\boldsymbol{R_\omega}^-$. Another extreme case, when both components are equal, means that orbit degenerates into a straight line form. And there is no need to view multiple filtered orbits plots with keyphasor marks, taken separately.

The full spectrum, unlike the common "half" spectrums of relative vibrations along each of two perpendicular directions, is a characteristic of some relationship between vertical ***Y*** and horizontal ***X*** vibration components, considered phase lag $(\boldsymbol{\alpha_\omega - \beta_\omega})$ between them. Besides, it is possible to see the precession direction of each twofold spectral component from the plot, and that is very important for example in case if any available shaft rotation speed signal is absent.

The paper presents some results of journal supports vibration investigations to diagnose centrifugal force-pump operating status of gas transportation train when its state has deteriorated and bearing defects arisen and grown. As a matter of fact, there were some complicative accompanying factors: the standard monitoring system installed had returned only current (not averaged) spectrums and wave forms and had no keyphasor signal on its output.

Field support relative data which had been obtained 8 days before an emergency breakdown of the unit are presented at Fig.1. Here the common spectrums **Sx** and **Sy** of horizontal and vertical vibrations respectfully are given in the upper part of diagram, and one could see fundamental frequency components of shaft rotation $\mathbf{f_r}$= 87.5 Hz and its low level harmonics and subharmonic (0.5 $\mathbf{f_r}$). The full spectrum **(R-, R+)** plot within frequency band -400… + 400 Hz is shown beneath.

The symptom of residual imbalance of shaft is manifested at both spectrums type (and is emphasized at bottom picture with much bigger forward component $\mathbf{f_r}$), but in full spectrum presentation there are obvious signs of light partial rub as well: subharmonic (0.5 $\mathbf{f_r}$) vibration has components both forward and reverse, and the last one is dominant. Presence of high harmonics is additional confirmation of the diagnosis.

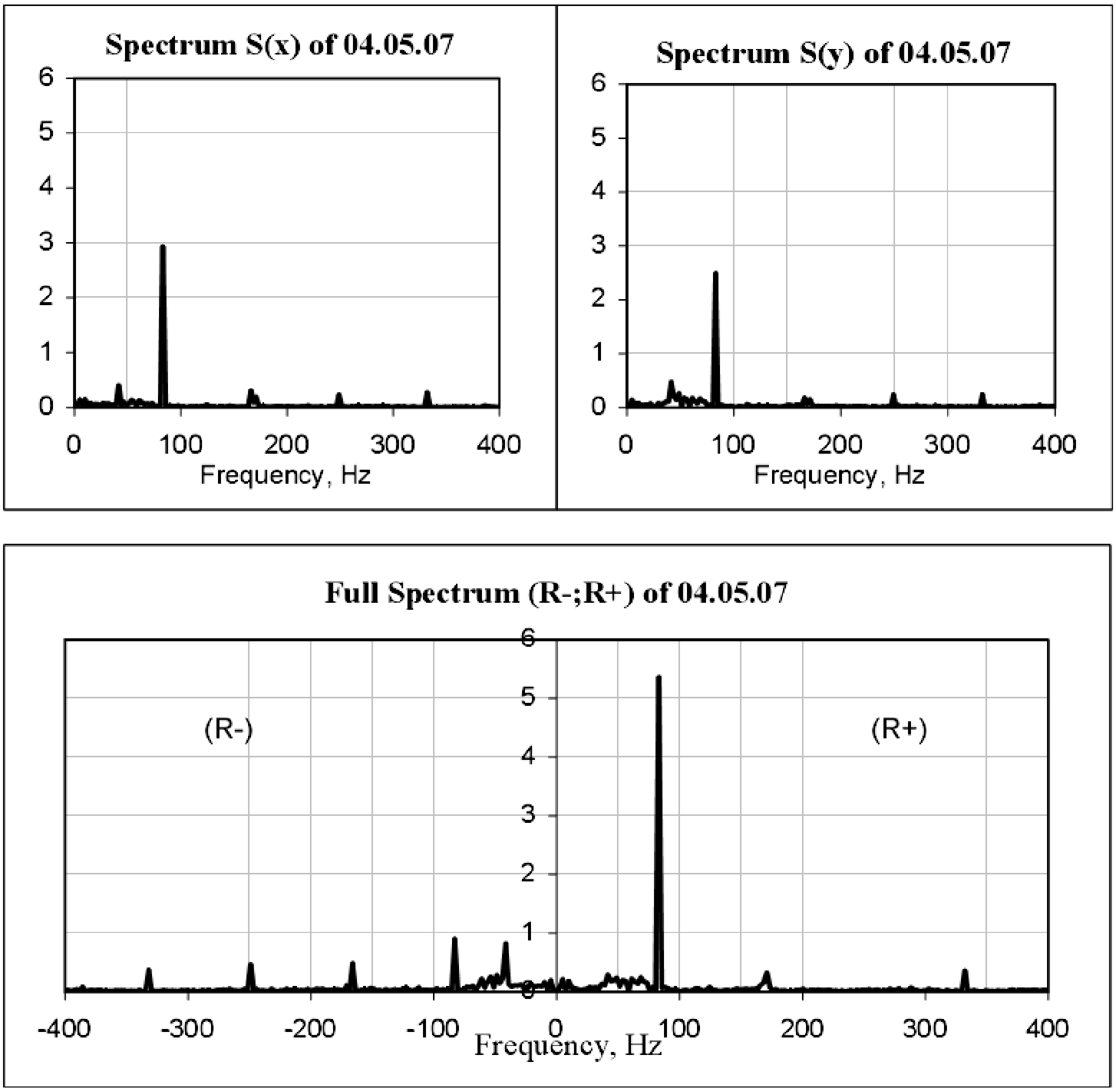

*Fig.1. Spectrums of horizontal **Sx** and vertical **Sy** relative vibrations of centrifugal force-pump field support (top) and corresponding full spectrum (bottom) seven days before machine emergency stoppage.*

Then, a day before the emergency stoppage of the engine due to failure of turbine gas generator roll bearing the spectrums had dramatically changed (Fig.2). The spectrum lines of $2/3\mathbf{f_r}$ which emerged and became dominating in "half" spectrums are signs of partial rub, but only full spectrum gives us direct evidence of the defect due to there are about equal forward and reverse components of that frequency. This may be an effect of dry friction which accompanies the rub and oscillations amplification near modified natural frequency of the machine part. Presence of forward and reverse harmonics of $\mathbf{f_r}$ gives additional confirmation of the diagnosis. As for the subharmonic frequency shift from $0.5\mathbf{f_r}$ to $2/3\mathbf{f_r}$, that is a consequence of dynamic stiffness changing due to rub development, and, accordingly with this process, self-adjusting of the machine part natural frequency.

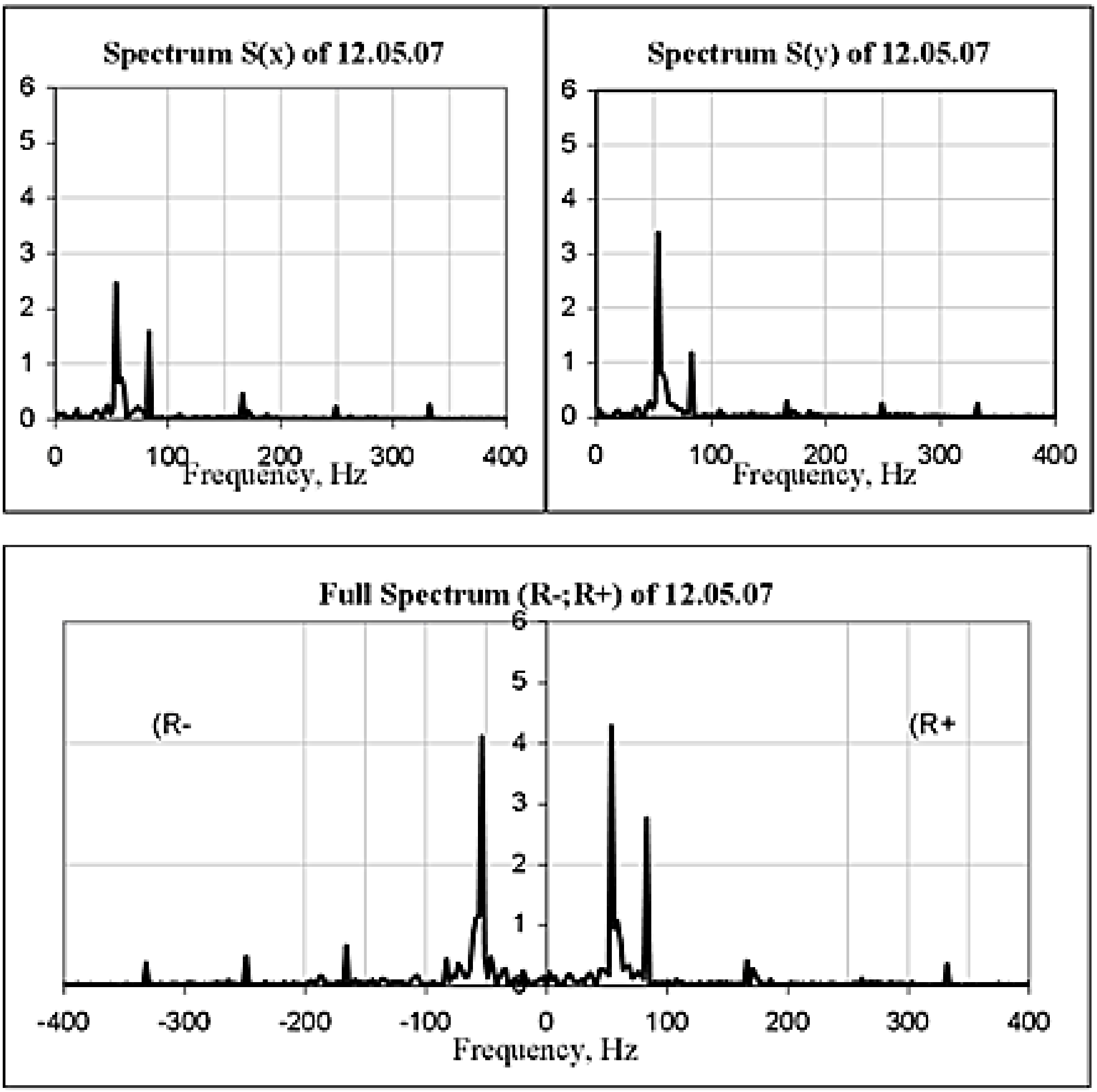

*Fig.2. Spectrums of horizontal **Sx** and vertical **Sy** relative vibrations of centrifugal supercharger field support (top) and corresponding full spectrum (bottom) one day before machine emergency stoppage.*

Plots of raw and filtered orbits corresponding to the “half” and full spectrums presented above give the additional evidences of the diagnosis described.

The orbit obtained within span 0…4.0 kHz is highly stretched in one direction, the oscillations are resonant, and horizontal and vertical ones are out of phase (see Fig.3).

Orbit filtered around $\mathbf{f_0}$ = 55 Hz ($\mathbf{\Delta f}$=50…60 Hz) (see Fig.4) shows, in accordance with full spectrum data, that shaft swings like pendulum under influence of serial opposite shock excitement due to rub following one for another with the natural frequency.

Orbit filtered around shaft rotation frequency is wide ellipse (see Fig.5) as it should be when some imbalance is present.

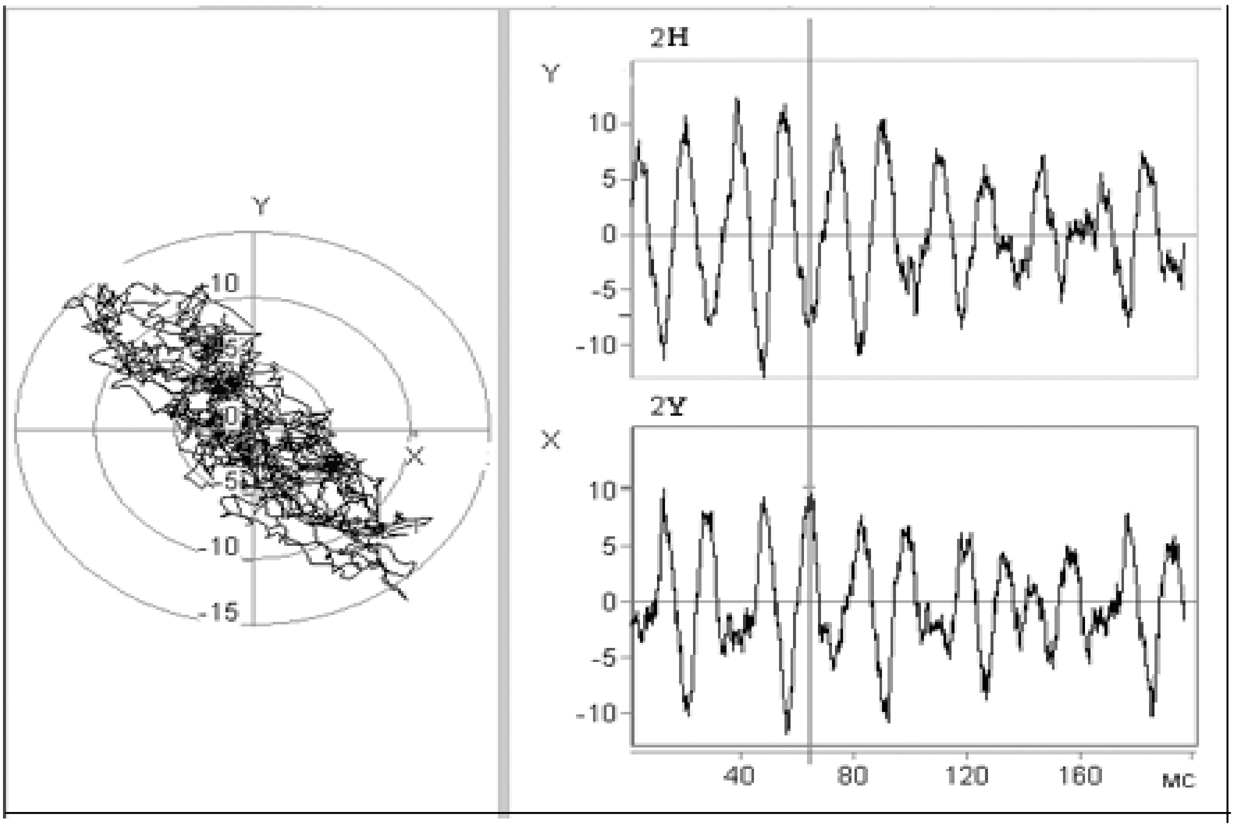

Fig.3. Raw waveforms and orbit of the same (see Fig.2) horizontal and vertical relative vibrations.

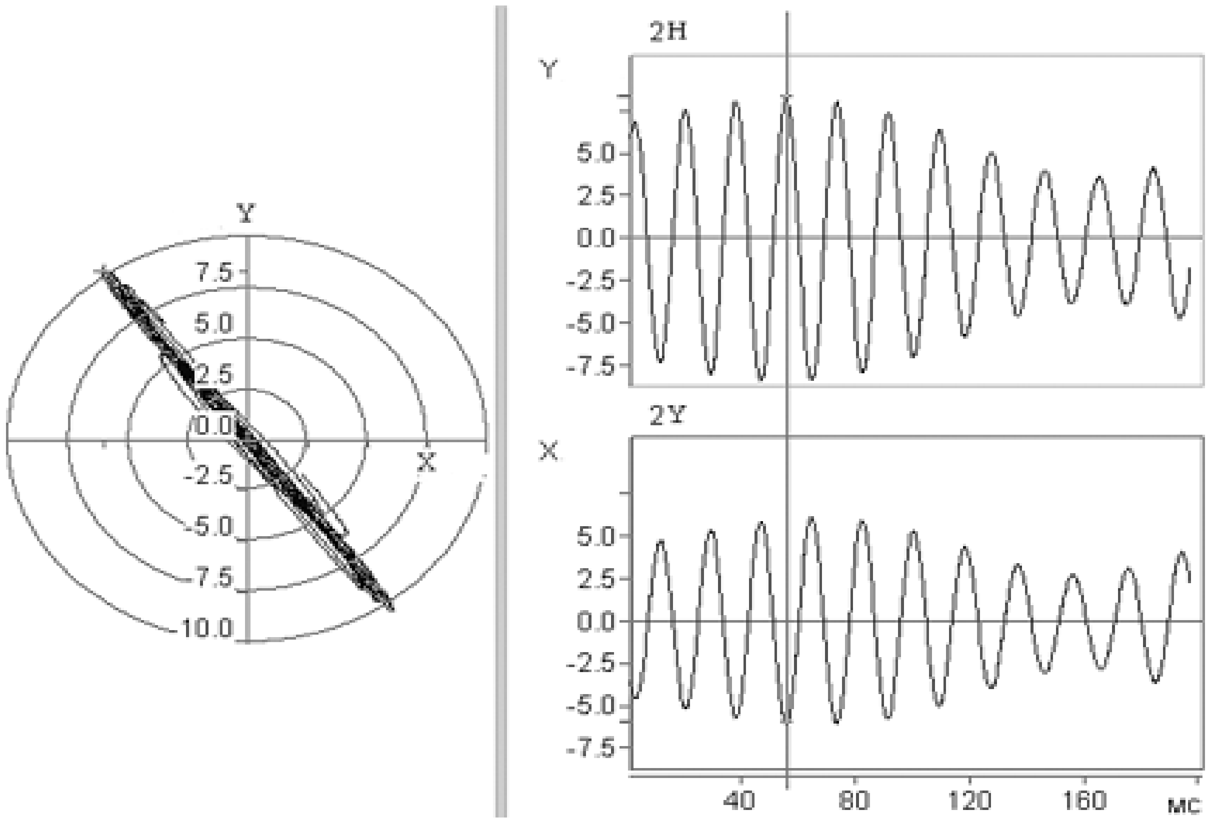

Fig.4. Filtered waveforms and orbit for only share of vibrations (see Fig.4) around frequency $\boldsymbol{f_o}$ *= 55 Hz*

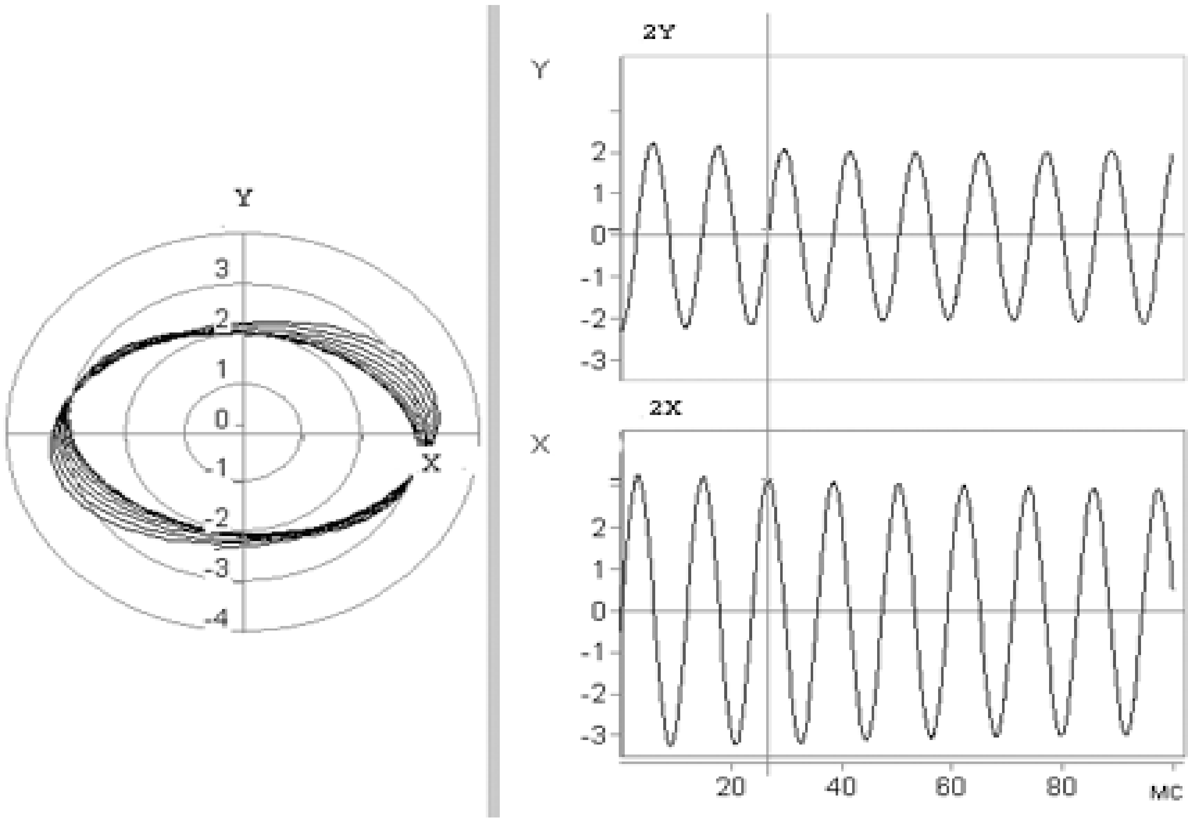

Fig.6. Filtered waveforms and orbit for only share of vibrations (see Fig.4) around frequency $\boldsymbol{f_r}$ =87.5 Hz.

Conclusions. The full spectrums are the power tool of relative vibration analyzing and present good and effective addition to other vibration features common used for condition monitoring, and could be recommended to more wide application. More than that, its calculation algorithm is simple and fast enough when FFT is using.

References:

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