FULL SPECTRUM ANALYSIS IN JOURNAL BEARING DIAGNOSTICS

Jiří Tůma and Jan Biloš
VŠB-Technical University of Ostrava
17. listopadu 15, 708 33 Ostrava, Czech Republic, jiri.tuma@vsb.cz

Abstract: The topic of the paper deals with full spectrum evaluation. The full spectrum plays a key role in the processing of complex signals. The real part of this kind of signals is a displacement in the X-direction while the imaginary part is a displacement in the perpendicular direction, as we say in the Y-direction. A good example is a shaft rotating in the journal bearing. The shaft displacements can be detect by proximity probes in the range of 0.1 mm. The spectrum analysis results in full spectra.

Keywords: Full spectrum, diagnostics, Journal bearings, orbit

1. Introduction

Full spectrum plots have recently received a great importance in rotors and journal bearings diagnostics thanks to research work that was done at Bently Rotor Dynamics Research Corporation and Bently Nevada Corporation. Related work done in Korea and the People's Republic of China must be mentioned [1, 2]. This article discusses the benefits of full spectra and how to use full spectrum plots in a machinery diagnostic analysis for fluid-induced instabilities.

In contrast to the frequency spectrum of a simple time signal the full spectrum is a tool for processing a two-coordinate signal. The one-coordinate signal gives information about motion along a strait line as for instance acceleration signal while the two-coordinate signal

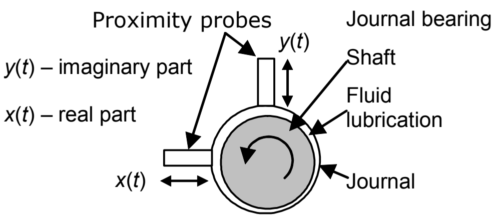

Fig. 1 Instrumentation arrangement

describes the motion of a point in a plane. The topic of this paper is focused on the motion of shafts in journal bearings. Measurement instrumentation is shown in figure 1. Proximity probe is a non-contacting device, which measures the displacement motion and position of an observed shaft surface relative to the probe mounting location. Typically, proximity probes used for rotating machinery measurements operate on the eddy current principle, and measure shaft displacement motion and position relative to the machine bearings or housing. In addition to the shaft displacements one per the shaft revolution voltage pulse, called the phase signal is used primarily to measure shaft rotative speed and serves as a reference for measuring vibration phase lag angle. It is an essential element in measuring rotor slow roll bow or runout information.

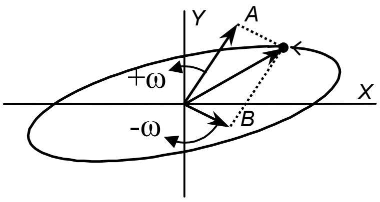

Fig. 2 Model of orbit construction

The simplest signal can be constructed in a complex plane from two vectors, **A** and **B**, rotating in opposite direction at the same angular frequency ω. The sum of these vectors is a vector parallel to the real axis only if both the vectors are the same and the initial phases are opposite. The resulting vector is a model of a real harmonic signal (sine or cosine function). In the case that these additional conditions are not fulfilled the sum of both vectors describes an ellipse, called an elementary orbit. The principle of the orbit construction is shown in figure 2. As the plane is complex, the vector **A** + **B** is a complex quantity. The real part of this vector is a time signal $x(t)$ while the imaginary part is a time signal $y(t)$. The vector end point in the complex plane is a complex signal $x(t) + j\, y(t)$ giving information about the shaft centre position, where j is the complex unity.

It is well known that the Fourier transform of the harmonic signal is a complex conjugate symmetric function of the frequency ω. This is a reason that the frequency spectrum is plotted only for the positive value of the frequency. If the time domain signal is a complex signal then the frequency domain function is non-symmetric and the plot of the magnitude of the complex number against the frequency is called a full spectrum. This spectrum contains both the positive and negative frequencies.

2. Orbit and full spectrum measurements

To study motion of the shaft in a journal bearing the Rotorkit device, product of Bently Nevada, was used. The proximity probes and the Keyphasor sensor belong to the instrumentation of Rotorkit (see figure 3). The shaft centre motion can be analysed only in the plane that is perpendicular to the shaft axis.

The RPM profile determined the shaft operation condition. The run-up is the first stage of the test continuing after a delay to the

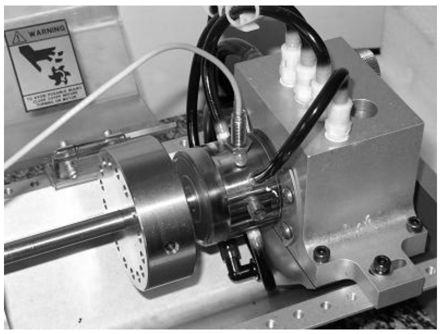

Fig. 3 Bently Nevada Rotorkit

second stage that is a coast-down. The RPM as a time function is shown in the upper part of the figure 3. The corresponding displacement in direction X is shown in the lower part of the same figure. As it is obvious a fluid-induced instability, commonly referred to as oil whirl, is the special dual resonance condition with the frequency that is proportional to the rotational speed.

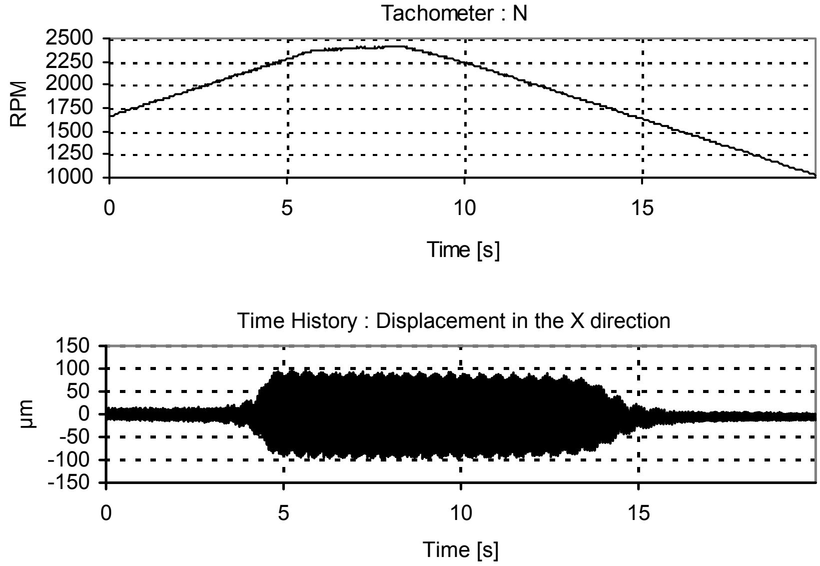

Fig. 4 RPM and X-axis displacement time history

A full multispectrum of the signal $x(t) + j\,y(t)$ composed from full spectra is shown in figure 5. The multispectrum frequency axis is in Hz. The orders 1 and 2 of rotational speed form a line of spectrum peaks determining the instantaneous RPM.

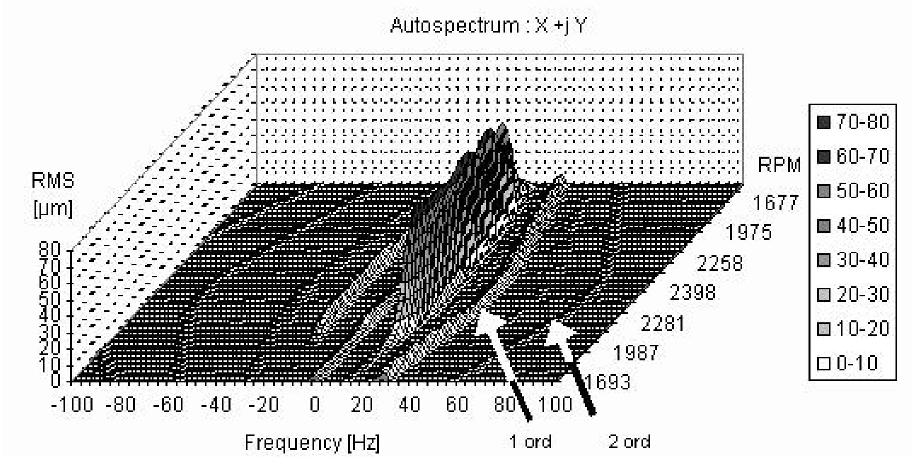

Fig. 5 RMS Full multispectrum of position signal $x(t) + j\,y(t)$ in Hz

The analysis in the term of revolutions and order gives better and clearer information about the shaft behaviour than the time or frequency in Hz. After resampling both the signals $x(t)$ and $y(t)$ to the sampling frequency that is proportional to the rotational frequency the shaft displacement in the both directions is a function of dimensionless revolutions. The real and imaginary part of the complex resampled signal is shown in figure 6. 10 revolutions of the rotor shaft correspond to less than 5 runs, called precession, along the elementary orbit. The shapes of the orbit for the different value of RPM are shown in figure 7 and 8.

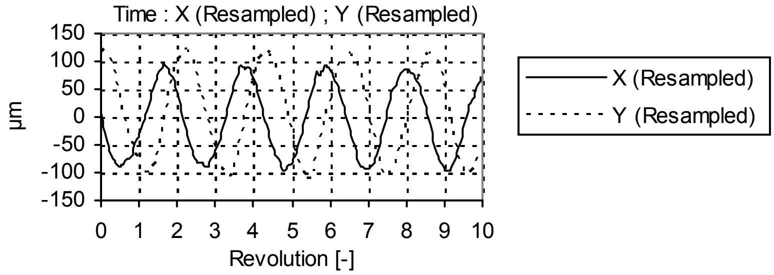

Fig. 6 Displacement $x(t)$ and $y(t)$ during 10 revolutions at 2400 RPM beginning at 6.78 s

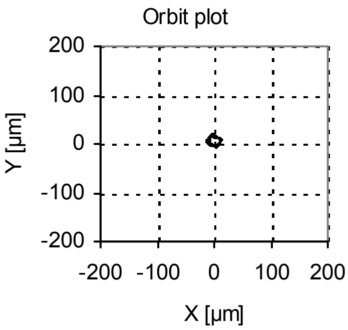

Fig. 7 Orbit plot beginning at 0 s

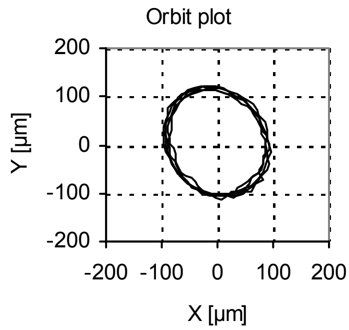

Fig. 8 Orbit plot beginning at 6.78 s

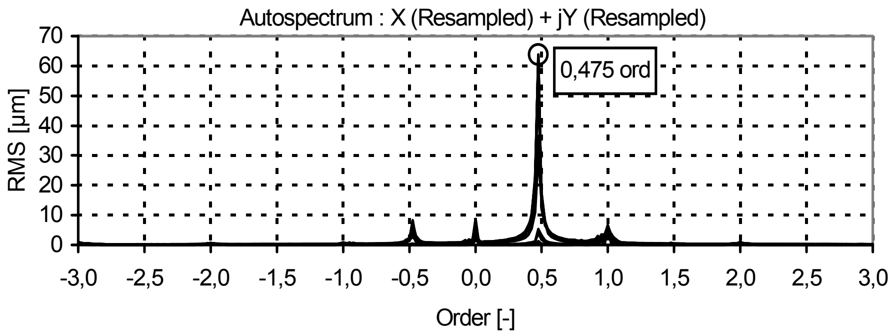

Fig. 9 RMS Full multispectrum of position signal $x(t) + j\,y(t)$ in orders

The frequency of the dominating components in the full multispectrum in figure 9 is equal to 0.475 ord (0.025 ord resolution). This subharmonic component in relation to the shaft rotational frequency is corresponding to shaft precession. The frequency 0.475 of the precession speed, designated by λ, is related to the shaft rotational speed. The shaft precession is self-excited by fluid induced instability and it is called whirl vibration. The ratio λ is in relationship with average ratio of circumferential velocity of oil flow in the space between shaft and journal to the shaft circumferential velocity. The whirl vibration is always forward precession and starts at the rotational frequency that is called Bently and Muszynska threshold. The orbit shape is nearly circular for whirl vibration. A reader should note that that the RPM threshold is different for run-up and coast-down.

The multispectrum as a waterfall plot, corresponding to the full multispectrum in figure 9, is shown in figure 10. As the dominating peaks in this contour plot form a line perpendicular to the frequency axis the multispectrum can be taken as an experimental verification of the fact that the value of λ is constant and independent on the shaft rotational speed.

As it is demonstrated in the Rotorkit description when the rotational speed exceeds the value of 3000 RPM the whip vibration appears.

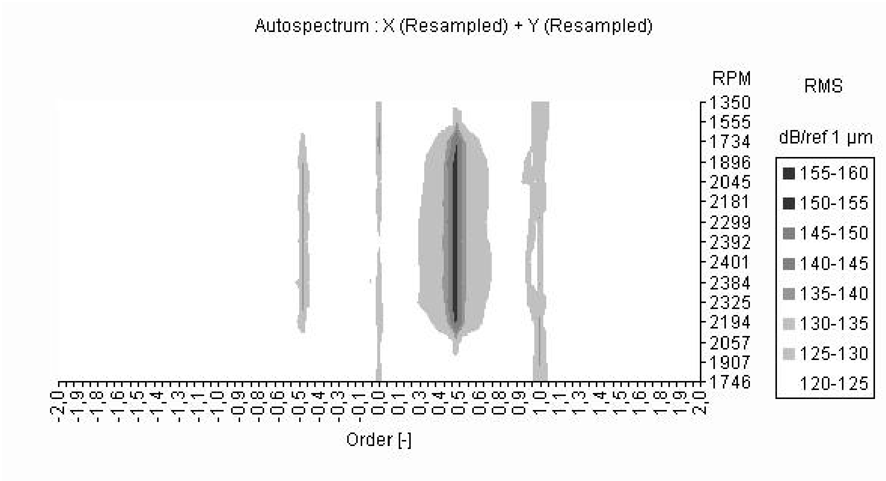

Fig. 10 RMS Full multispectrum of position signal $x(t) + j\,y(t)$ in order as waterfall plot

5. Conclusion

The paper describes a powerful analytical tool for rotor system diagnostics. The new term is a full spectrum. The full spectrum is a good tool for studying rotor instability in journal bearings. The paper demonstrates whirl vibration and the independence of the ratio relating the precession speed to the shaft rotational speed on the shaft absolute rotational speed.

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This research has been conducted at the Department of Control Systems and Instrumentation as a part of the research project No. 101/04/1530 and has been supported by the Czech Grant Agency.