Application of the wavelet analysis in investigations of machine vibrations in run-up or run-down conditions

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Abstract: Investigations of the rotating machinery in transient conditions are interesting due to identification capability of resonance properties of the object. One of the ways of diagnostic investigations in transient conditions is research during run-up and run-down. The recorded vibrations in this kind of conditions are non-stationary and are the result of different phenomena. The estimation of vibration signals from the machine observed during run-up or run-down is difficult. The detection capability of the different phenomena, requires a method which enables to obtain time-frequency results. At present, the analysis of these signals is based on the Short Time Fourier Transform (STFT). The most interesting, for these applications, are methods based on the Wavelet Transform (WT).
The paper deals with the application of the wavelet transform to detect resonant phenomena and typical faults of rotating machinery. A method of the diagnostic investigations of rotating machinery based on the wavelet transform consists in the realization of two stages. The first one deals with the application of the wavelet analysis for the estimation of the vibration signals. The most important in this stage is synchronization of analysis parameter (scale) to the varying rotating speed of the shaft and the choice of optimal basis function. The second stage consists in application of the RLS analysis which is grounded on the hypothesis concerning the possibility of decomposing frequency spectra into two parts: part of signal depending on variable conditions of machine action and part which is independent from these conditions. The results of applications of both analyses are presented. CSCC'99 Proc.pp.5221-5224

Key-Words: rotating machinery, variable action of machine, symptom, separation of symptoms

1 Introduction

Investigations of rotating machinery may with respect to operating conditions be divided into ones in fixed or transient conditions. The fixed conditions means, for example, the constant speed, the constant sub-assembly temperature, the constant oil temperature and so on. The transient state can be characterized by variability of above mentioned parameters. Investigations in transient conditions are more interesting due to identification capability of resonance properties of the object. The main goal of this investigations is, in particular, variability identification of these properties. The resonance property variation can be caused by the fatigue crack of the shaft, the presence of excessive backlash, the variability of bearing operation or the crack in machine foundation. One of the ways of diagnostic investigations of the rotating machinery in transient conditions is research during run-up and run-down. In this case, the role of a vibration exciter is played by the machine itself, especially residual unbalances that are always present. This kind of method has a lot of advantages. The most important are that it is not necessary to stop the machine and that the observation of machine's response may be carried out under different, often nonstationary excitations. The vibrations in this kind of conditions are non-stationary due to several reasons, such as dependence of statistical characteristics of signal (mean or root mean square value) from time. Moreover, these vibrations are the result of different phenomena (resonance phenomena, phenomena which take place in the neighborhood of machine, phenomena related with rotating of machine elements, friction or impact).

2 Analysis of the vibration signals

Knowledge on phenomena occurring in subassemblies of the rotating machinery allows us to say that the kind of the signal discussed above contains:

- the narrow-band, constant frequency components - the results of resonance phenomena, or phenomena which take place outside of the machine,
- the narrow-band, variable frequency components - the effect of phenomena related to the rotation of the machine elements,
- the wide-band components, which are caused by friction or impact.

The estimation of vibration signals from the machine observed during run-up or run-down is difficult. The detection capability of the above mentioned phenomena, requires a method which enables to obtain time-frequency results. The time-frequency representation enables not only the detection of signal components but, first of all, the exploration of their variability in time. At present, the analysis of these signals is based on the Short Time Fourier Transform (STFT). This method consists in signal estimation in small time segments, but their width is constant. Shortcomings of this method are known very well.

There are a lot of methods described in the bibliography dedicated to non-stationary signal analysis that lead to time-frequency representation [2] [3] [4]. Some of them have applications in diagnostics of machinery. The most interesting, for our applications, are methods not requiring compromise between length of time segment and frequency resolution. The wavelet transform (WT) is an example of analysis of this type. The essence of this method is the fact, that wavelets offer another advantage, i.e. the frequency localization is logarithmic, that is, proportional to the frequency level. As a consequence, time localization is better in the highest frequencies. It makes this method more useful for non-stationary signal analysis, in particular, for estimation of components with different time scale. These components are the results of phenomena with different time duration. Transient conditions of rotating machinery operation are examples of these phenomena.

The initial investigation having the qualification of WT in rotating machinery diagnostics in view, have brought good effects. The analyzed signals were generated in laboratory conditions on the ground of knowledge of rotating machinery operation and were recorded during action of a laboratory stand named RotorKit and during action of a turbocompressor. The comparison between the WT results and the STFT results showed great capability of wavelets application.

3 Application of the wavelet analysis

The analysis based on the wavelet transform is especially dedicated to analysis of nonstationary signals, particularly with different time duration of phenomena generating these signals. The most promising in application of this method is a choice capability of parameters of the wavelet analysis. This problem deals with values of scale parameters as well as choice of optimal basis function.

3.1 The choice of scale parameters

The best resolution in analysis of signals recorded during run-up or run-down conditions is synchronization of varying machine action parameters with parameters of analysis. The concept of changes of this parameter requires some assumption. The most important is a kind and way of registration of unstable values, which can characterize of varying machine action. It seems, in the rotating machine case, the simplest way is the observation of rotating speed, particular, its variability. It can be realized be recording of e.g. tachometric signals. As above-mentioned, because of always present residual unbalances, the main signal component is related to the rotational speed during the rotating machine action. The investigations described in the paper contain the synchronization of temporary rotating speed with scale values of basis function. It is brought a very good effect.

3.2 The choice of basis function

The next problem of application of the wavelet analysis in run-up or run-down investigations of rotating machinery is the choice of the analyzing function. The most of identified phenomena taking place during action of rotating machinery has impact character. From this reason, it seems that the best solution, in this case, is the function which models transient behavior of object, such as impacts. The described in this paper investigations consisted in the application of a lot of different family of function (e.g. square, triangular, spline and their multiplication with harmonic function). The best results are obtained with using of an effect of multiplication of Gauss and harmonic functions. This function was using in the presented investigation.

There are examples of analysis of the vibration signal recorded during of run-up of laboratory stand RotorKit in a Fig. 1. This is an example of wavelet analysis with this synchronization of scale values to the values of the varying rotating speed.

The horizontal axis of this scalogram is described by time and the vertical axis by the frequency. The rotating speed was changing from 300 to 6100 RPM. There are shown two signal components in Fig. 1. The first one is an effect of unbalances. Frequency of these component is to the equal rotating frequency. There is very distinct resonance about 60 [Hz].

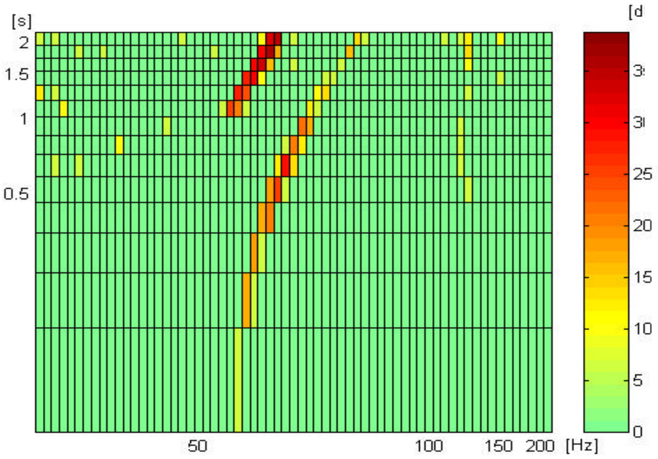

Fig.1 Scalogram of the vibration signal recorded during run-up of the RotorKit stand

The second signal component is the result of oil whirl in the hydrodynamic bearing. That synchronization of the scale parameter to the varying conditions of the machine action makes the run-up characteristics more readily.

4 The separation of identified symptoms

The run-up or run-down characteristics carry always information about signal components and their variability in time. A precision of the signal estimation is depended on the method of its analysis. However, in each case results of time-frequency analysis give information about all components e.g. related and not related to the varying conditions of machine action.

In the most cases these characteristics can by interpreted only be human expert. The most interesting is, the investigations can include application of the RLS method [1].

This method is grounded on the hypothesis concerning the possibility of decomposing results of time-frequency (or time-scale) analysis into two parts: the part of signal depending on variable conditions (Fig.2) of machine action and the part which is independent from these conditions (Fig.3).

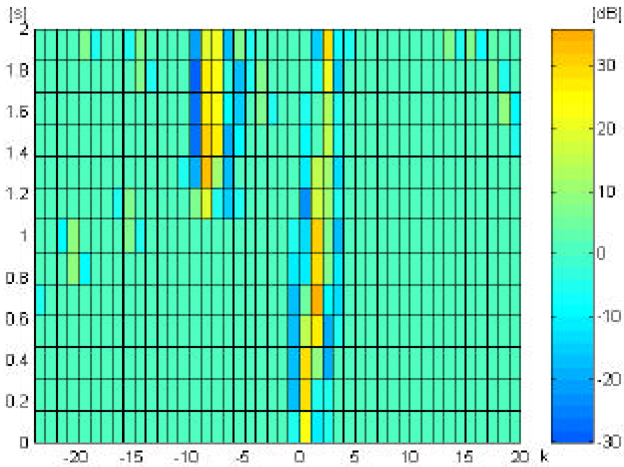

Fig.2 Part of signal related to the variability of rotating speed

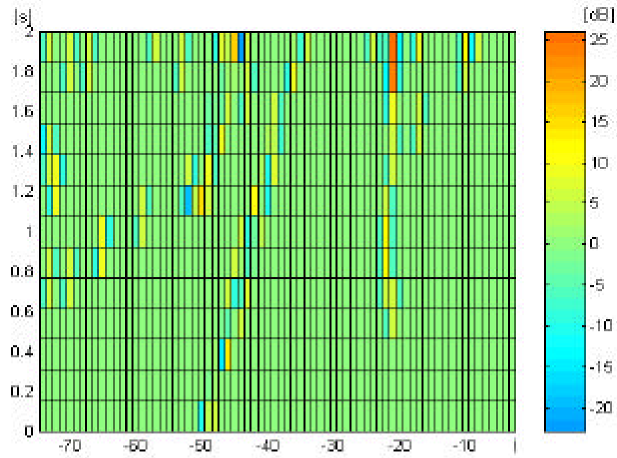

Fig.3 Part of signal not related to the variability of rotating speed

The results of the application of the RLS analysis are presented in the Fig.2 and Fig.3. The first figure shows two signal components: effects of unbalances and oil whirl. The second figure can make possible identification of the signal component related to the occurrance of oil whip. This component was not visible on the scalogram.

4 Conclusion

The application of the wavelet analysis in investigations of run-up or run-down of rotating machinery make possible to detect of symptoms of different phenomena taking place during machine action. Moreover, application of this analysis unables us to apply the method of separation of these symptoms, which can be used as input data in systems of automatic decision making.

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