DYNAMICS OF A ROTOR IN ROLLER BEARINGS

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Abstract

This paper describes a nonlinear model of rolling bearing with clearance. The rotor dynamics software Dynamics R4.2 includes this model for design and analysis of complex rotor systems, results are applied to a rotor system analysis. The analysis includes influence of the bearing clearance upon vibration signals together with the weight and damping loads.

Theory

Vibration diagnostics systems are essential parts of efficient machine operating. Specific indicating signals provide information on the current machine status but the signals evaluation is a labor and time consuming job. It is possible to find the signal level by a special test with introduction of a failure into the operating machine. This expensive test may be replaced with an advanced computer simulation that provides specific diagnostics algorithms.

This paper is devoted to relations between the bearing support parameters and the dynamic system response. This problem is actively reviewed by many authors. Australian team of N.S. Feng, E.J. Hahn и N.B. Randall [1] has developed a bearing model basically used in this paper. We have improved this model as to introduce it into the "Dynamics R4.2" S/W which is applied to investigation of the bearing clearance influence.

A generalized equation of the rotor system motion including the bearings may have the following form:

$$M \cdot \ddot{X} + C \cdot \dot{X} + K \cdot X = F_U + F_B + W \,, \quad (1)$$

where

M – inertia matrix,

K – stiffness matrix,

C – damping and gyro effect matrix,

$\ddot{X}, \dot{X}, X$ – columns of accelerations, velocities and motions respectively,

F_U – column of unbalance loads,

F_B – column of bearing forces dependent upon the velocities and motions,

W – weight load.

The bearing forces depend upon the velocities and motions, so the accurate solution of this equation requires a non-linear approach.

The bearing model (picture 1) is based on the following assumptions:

- the surface contact is described by Hertz theory;
- the roller inertia is not considered;
- the damping is linear;
- all kinds of sliding are not considered.

Then the equation to desribe contact forces of the roller interaction with the ring is:

$$\begin{Bmatrix} F_x \\ F_y \end{Bmatrix} = K_H \cdot \sum_{i=1}^{N} \beta_i \cdot A^{3/2} \cdot \begin{Bmatrix} \cos\theta_i \\ \sin\theta_i \end{Bmatrix}, \quad (2)$$

Where K_H – contact stiffness coefficient;

$A = x \cdot \cos\theta_i + y \cdot \sin\theta_i - \delta$; $x = x_1 - x_2$, $y = y_1 - y_2$;

$$\begin{cases} \beta_i = 1, \text{ at} > 0 \\ \beta_i = 0, \ at \ A \le 0 \end{cases}$$

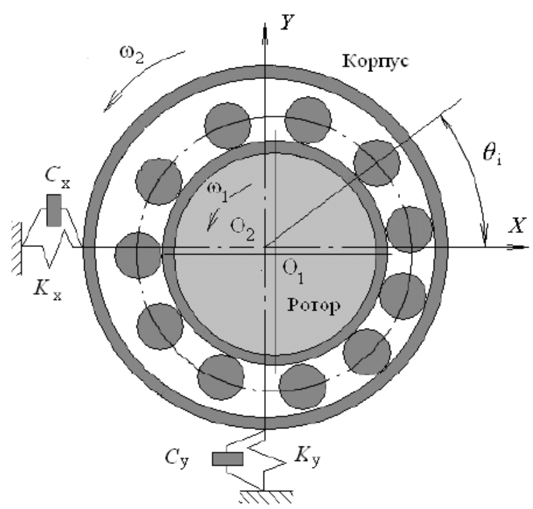
δ – bearing clearance,

$$\theta_i = \frac{2\pi}{N}(i-1) + \omega_c \cdot t$$

ω_c – separator rotation speed.

$$\omega_c = \left(1 - \frac{D_b}{D_p}\right) \cdot \frac{\omega_1 - \omega_2}{2} \quad (3)$$

where D_b – ball diameter; D_p – balls centerline circle diameter.



Picture 1 – bearing model

According to [2] the contact stiffness is

$$K_H = \left(\frac{1}{\frac{1}{K_i^{2/3}} + \frac{1}{K_o^{2/3}}} \right)^{3/2}, \quad (4)$$

In this equation the stiffness coefficients K_i and K_o are determined by the bearing dimensions.

The linear damping components are added to the bearing forces

$$\begin{Bmatrix} F_x \\ F_y \end{Bmatrix} = \begin{Bmatrix} F_x \\ F_y \end{Bmatrix} + C_b \cdot \begin{Bmatrix} V_x \\ V_y \end{Bmatrix}, \quad (5)$$

where C_b – damping coefficient, V_x, V_y - relative velocities.

$$V_x = V_{x1} - V_{x2}; \quad V_y = V_{y1} - V_{y2}$$

For a roller bearing the stiffness coefficients and deformations are calculated by a similar equation

$$\begin{Bmatrix} F_x \\ F_y \end{Bmatrix} = K_H \sum_{i=1}^{N} \beta_i \cdot A^{10/9} \cdot \begin{Bmatrix} \cos\theta_i \\ \sin\theta_i \end{Bmatrix} \quad (6)$$

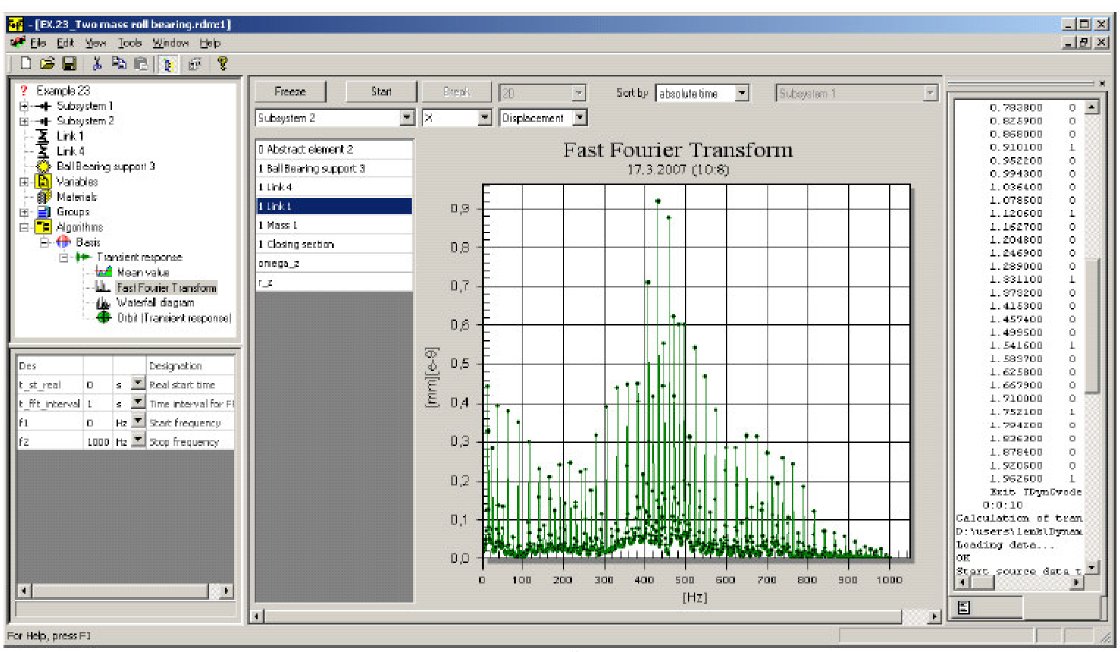
Results of analysis

An input data example is shown in Table 1. The data is similar to [1] except the low rotor speed where the unbalance loads are small and do not violate the rotor spinning.

Table 1

Parameter	Unit	Value
Housing mass	Kg	10
Support stiffness	N/m	$2*10^8$
Support damping	N*s/m	1000
Rotor mass	Kg	3
Rotor rotation frequency	Hz	3
Rotor unbalance	G*cm	0
Bearing mean diameter	mm	52
Ball diameter	Mm	11.9
Number of balls		11
Groove radius	Mm	6.16
Contact angle	deg	18
Bearing damping	N*s/m	2940
Ratio of the ball spinning frequency on the outer ring (BPFO) to the rotation frequency		4.24

The system dynamic response is analysed by the "Dynamics R4.2" software. Picture 2 shows an example of the S/W dialogue window.

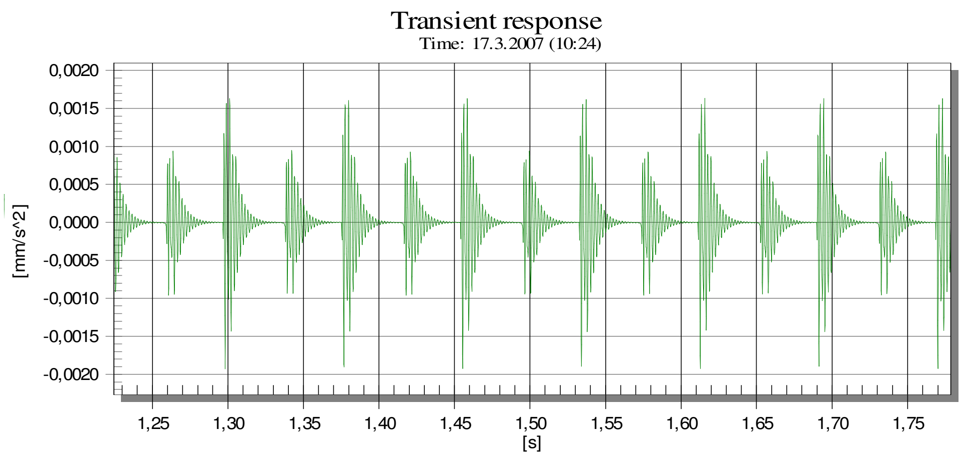


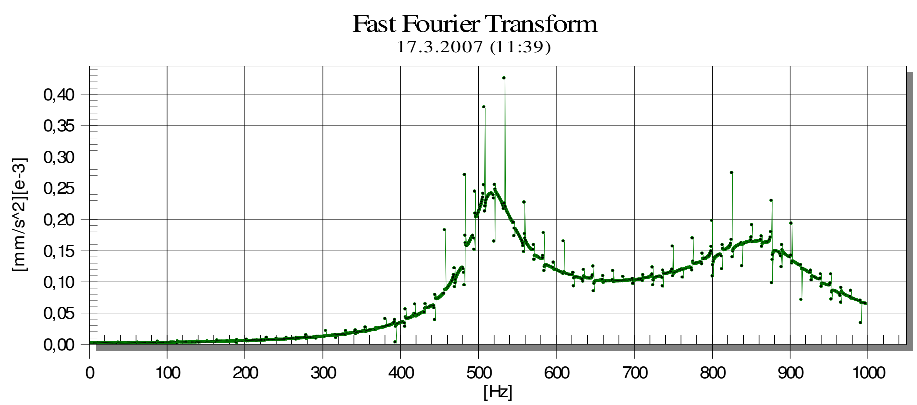
Picture 2 - Dynamics R4.2 window with the analysis results

The motion equations are integrated by the "CVODE" procedures [3] with the adoptive step selection on the 2 seconds time interval.

The analysis examples differ with the bearing clearance values of 0.00, 0.02 and 0.06 mm. The free casing natural frequency is 712Hz, or 42706rpm. Weight is the only considered load. The analysis results below are shown for the *Y* direction.

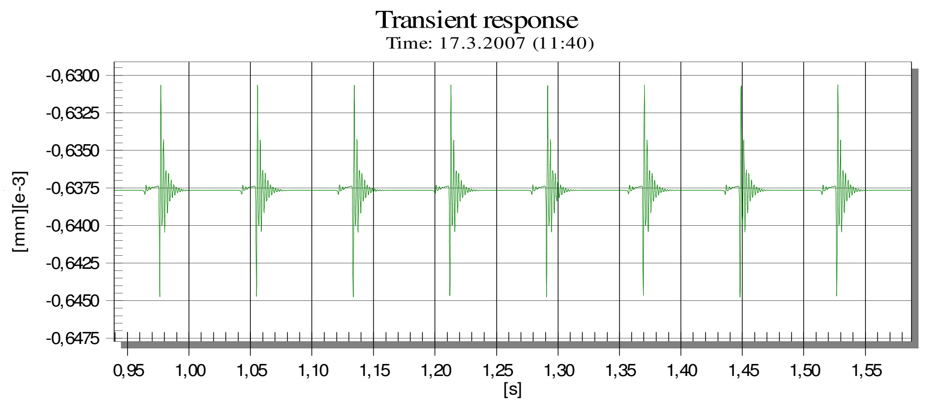
Picture 3 shows a time related signal and a frequency spectrum of a casing acceleration. The bearing has a zero clearance. One can see two types of signal clusters with different magnitudes. The clusters time intervals are near to the BPFO frequency.



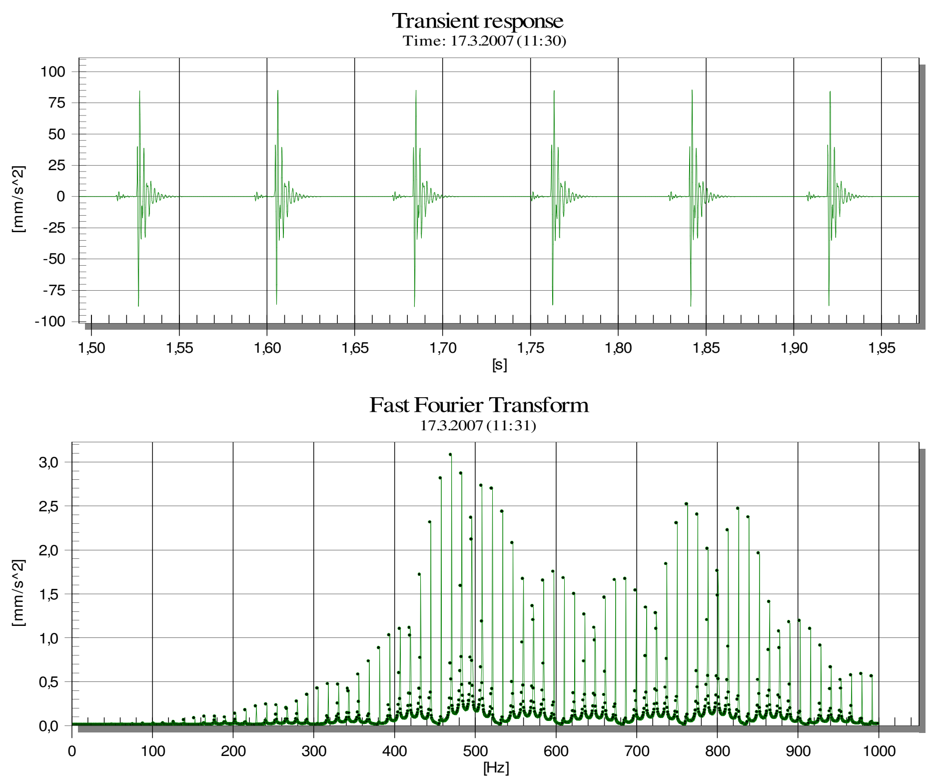


Picture 3 – time related signal and spectrum of the casing acceleration, bearing clearance 0.00

Pictures 4 and 5 show respectively time related oscillation magnitude, acceleration and spectrum of the system casing for the bearing clearance 0.02 mm. Every revolution of the rotor produces four clusters of pulses. Picture 6 shows a part of the spectrum. The clusters frequency is near to the bearing BPFO frequency. Also one can see frequencies even to the BPFO.

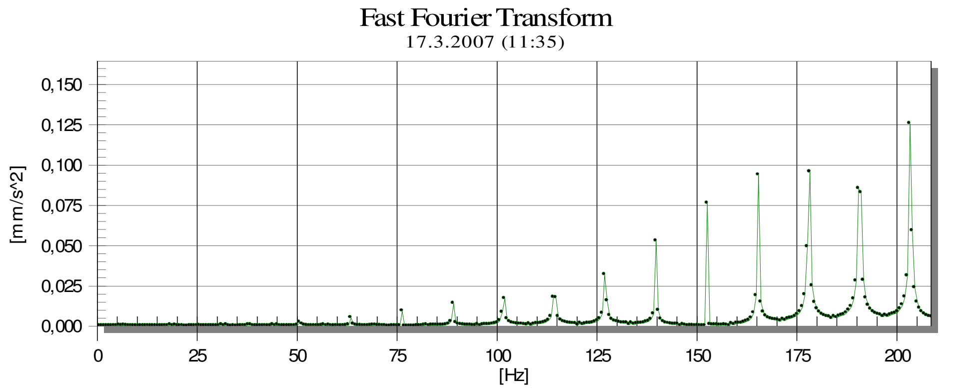


Picture 4 - time related signal of the casing motion, bearing clearance 0.00



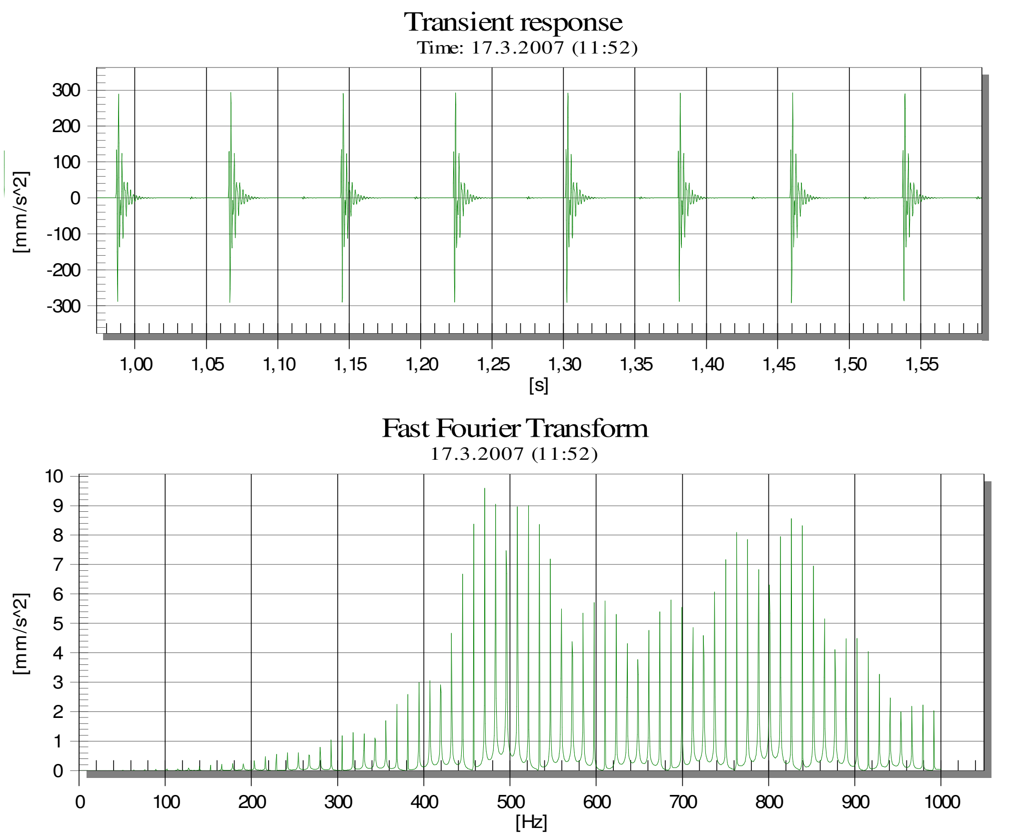
Picture 5 – time related signal and spectrum of the casing acceleration,

bearing clearance 0.02



Picture 6 –Part of the casing acceleration spectrum, bearing clearance 0.02

Calculation results for the bearing clearance 0.06 mm are given in picture 7.



Picture 7 – time related signal and spectrum of the casing acceleration, bearing clearance 0.06

The results above show complicated influence of the bearing clearance upon the dynamic system response. The different spectrums show frequencies of the bearing BPFO and its multiples. The vibration level in the "big clearance" bearing is remarkably higher than in the “normal clearance” one. Also one can see on-uniform increase of the BPFO multiples versus the clearance. Thus the high frequency signal analysis may be useful in the vibration diagnostics.

Conclusion

Numerical simulation of a bearing provides important specific features of a system vibration response. The simulation results may be useful in vibration diagnostics of complicated rotating systems.

References

1 N.S Feng, E.J. Hahn and R.B. Randall. Simulation Of Vibration Signals From A Rolling Element Bearing Defect (DSTO-GD-0262).

2 Бейзельман Р.Д., ЦыпкинБ.В., ПерельЛ.Я. Подшипникикачения: Справочник. 6-еизд., испр. идоп. –М.: Машиностроение, 1975. –572 с.

3 S.D. Cohen and A.C. Hindmarsh. CVODE, A Stiff/Nonstiff ODE Solver in C / Computers in Physics. – Vol. 10, No. 2 (March-April 1996). –pp. 138-140.