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CHAOTIC AND IRREGULAR MOTION OF ROTORS SUPPORTED ON JOURNAL BEARINGS

Włodzimierz Kurnik
Zbigniew Starczewski
Warsaw University of Technology
Institute of Machine Design Fundamentals
02-524 Warszawa, ul. Narbutta 84
Tel. +48 22 660 8619, e-mail zst@simr.pw.edu.pl

Abstract

In the paper a survey of problems related to journal bearing systems is briefly presented. The problems constitute one of the main subjects that have been dealt with in Institute of Machine Design Fundamentals at the Warsaw University of Technology. They focus on rotor system dynamics, stability, and bifurcation. In some of the works the rotor time responses revealing chaotic character were observed.

1. Introduction

Practically, every machine possesses bearings, i,e, kinematic couplings which enable elements to carry a loading and to work in relative motion. Reliability of the bearing systems (journal bearings) and their stable working results from a group of phenomena appearing in oil film between moving elements filling up the space called the bearing gap. Well known are advantageous effects brought about by presence of the oil film (durability, silent-running). Admittedly, there are some disadvantageous effects as well. Many breakups of turbogenerators, pumps, compressors, engines, and centrifugal separators used in nuclear industry comes from a bit too simplified, routine approach toward designing of journal bearings. Negligence of a series of dynamic phenomena pertaining to working of journal bearing systems bears its fruit sometimes when it comes to their long-term operation under nominal loadings. This makes researchers and engineers to continue theoretical and experimental studies on such systems. To help their endeavours computer technique has been successfully applied. It qualitatively enhanced the studies.

Routine calculations of the journal bearing systems generally disregard dynamic criteria and phenomena such as criticakl states, resonant amplitudes, self-excitation, vibroinsulation of the oil film, etc. Both theoretical and experimental investigations indicate that dynamics of the journal bearings depends upon numerous factors. The main among them are: rotor unbalance, internal friction, structural friction, rotor unsymmetry, visco-elastic properties of shafts, hydrodynamic uplift forces, dimensions and bearings clearances, presence of other machines working in direct neighbourhood. It may happen that all of these factors can appear simultaneously. An intensive course of examinations on the journal bearing systems have been taking place for years in Institute of Machine Dynamics Fundamentals at the Warsaw University of technology, led by Prof. Dr h.c. of Academy of Mining and Metalurgy Zbigniew Osiński. The examinations have been carrying out by a group of researchers from scientific teams that belong to Non-linear System Dynamics (Prof. W. Kurnik) and Dynamics of Journal Bearings Systems (Prof. Z. Starczewski) cooperatives. As an outcome a series of papers were published in Polish and foreign journals, many of the were presented at various conferences in Poland and abroad.

2. Carried-out investigations

Among the results of the investigations dedicated to journal bearings, enhanced by computer simulations, the existence of irregular time responses of rotor journals due to interactions with oil film (strongly non-linear hydrodynamic uplift forces) has been proved. These responses seem to reveal features typical for chaotic vibration. So far, the investigations of chaotic phenomena carried out in Institute of Machine Design Fundamentals have concentrated on the following problems:

1. Chaotic motion of symmetric rotors supported on journal bearings.
2. Chaotic motion of unsymmetric rotor systems.
3. Chaos in systems with rotor supported on journal bearings having non-circular contour.

The above-mentioned unsymmetry can be understood twofold:

- physical unsymmetry, related to properties of the supports themselves (different oil viscosities, bearings gaps, journal lengths),
- geometric unsymmetry, related to eccentric position of the rotor mass with respect to distance from the bearings.

For description of dynamics in these cases the, so-called, plane and short models of the journal bearings were used. Oil viscosity was assumed to be independent of temperature, journal position, and its velocity. If so, the oil film pressure distribution could be described by simplified Reynolds' equation (see Kurnik and Starczewski, 1984). Different boundary conditions for the squeeze and wedge effects were admitted. For journal bearings with non-circular contours (pericycloidal, with multiplication factor 3) an approximated method introduced by Kaniewski (1973) was incorporated. In effect static pressure distributions and load capacity was determined (see Osiński and Starczewski, 1998). The derived equations of motion, in analytical form, presented by Kurnik and Starczewski (1995), because of their complexity (strong non-linearities, couplings, many degrees of freedom due to unsymmetry) were then solved numerically within a wide range of structural and operating parameters.

3. Results of numerical simulation

Exemplary results of numerical simulation are presented in following figures.

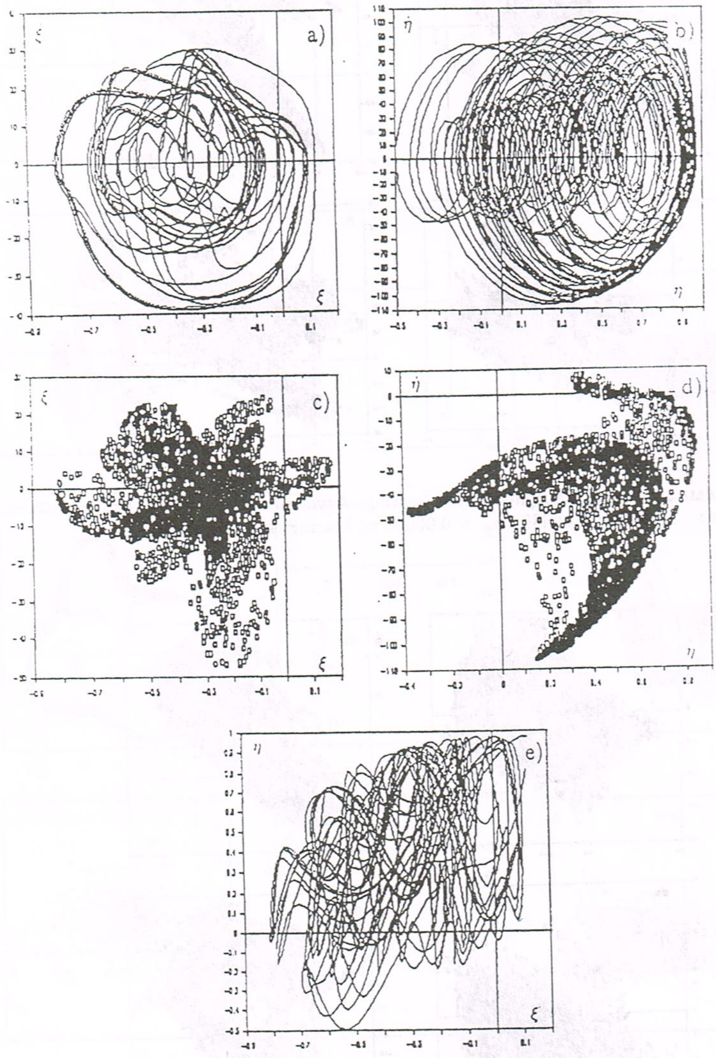

Fig. 1. Phase trajectories for both directions of the journal motion $4xi - \eta$ in rectangular coordinate system (a, b), Poincare's maps (c, d), journal trajectory (e). Assumed data: oil viscosity μ = 0.01 Pas, journal length l = 0.1 m, relative gap δ = 0.00897, transverse loading applied to the rotor Q = 300 N, rotor mass m = 200 kg, rotation speed ω = 296 1/s, frequency of kinematic excitation ν = 285 1/s, excitation amplitude a_w = 0.00008 m.

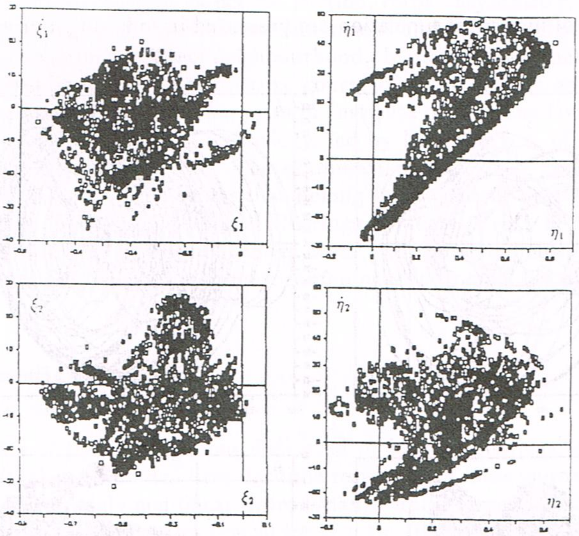

Fig. 2. Poincare's maps of the right and left bearing. Assumed data: $m = 200$ kg, $l = 0.05$ m, $\delta_1 = \delta_2 = 0.008897$, $a_w = 0.00008$ m, bearings span $L = 1$ m.

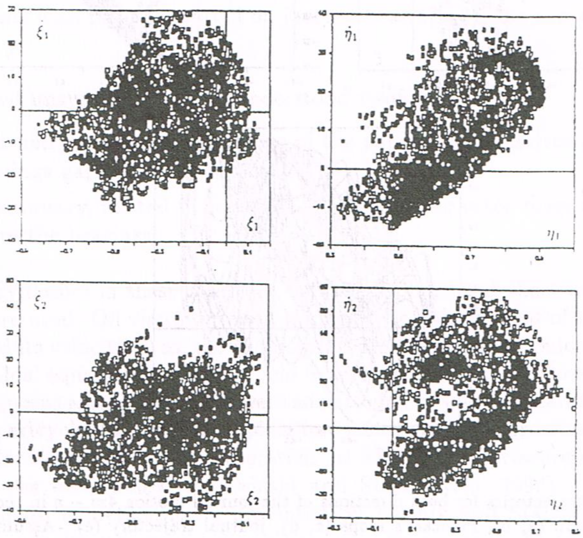

Fig. 3. Poincare's maps of the right and left bearing. Assumed unsymmetry: $\delta_1 = 0.01400$, $\delta_2 = 0.008897$

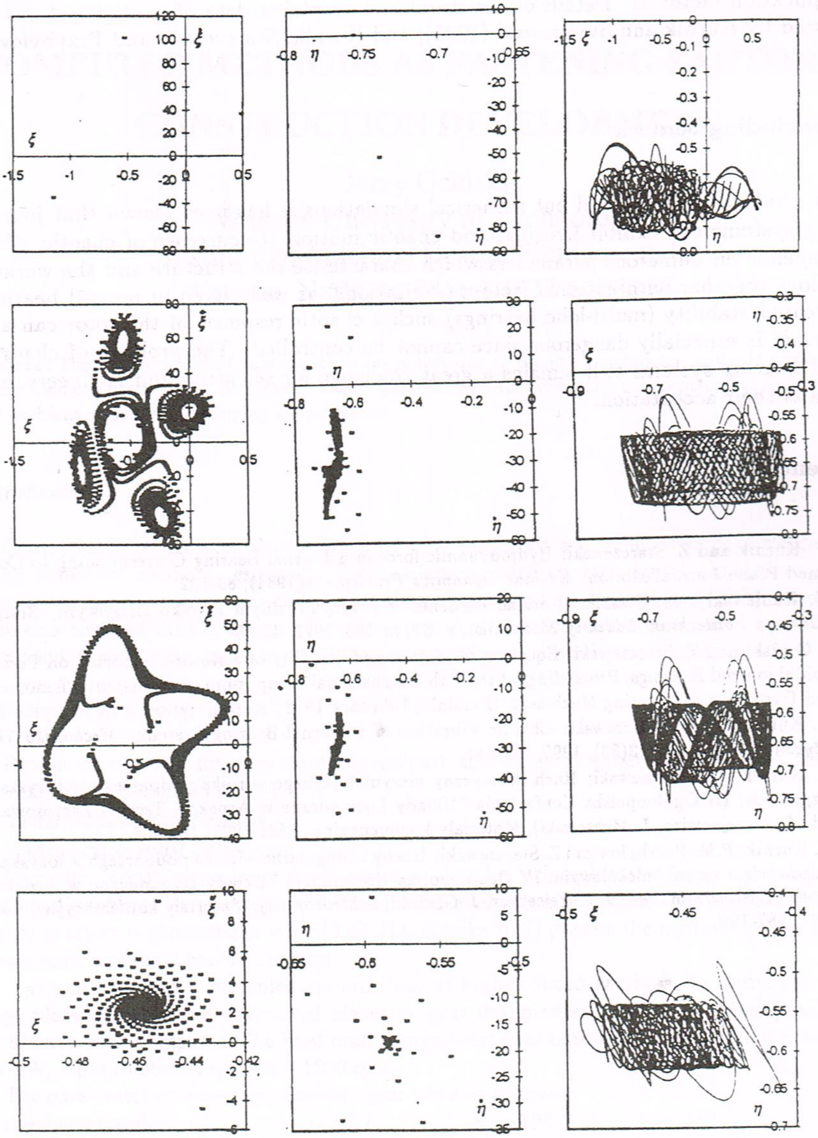

Fig. 4. Other exemplary journal trajectories and corresponding Poincare's maps.

Figure 1 presents the case of symmetric rotor supported by identical circular bearings, in Fig. 2 the rotor is unsymmetric (its mass center is shifted towards left about 15% of the bearings span), in Fig. 3 the bearings possess non-circular contour (pericycloidal with multiplication factor 3). Details of structural and opertaing data of quoted systems are discussed by Kurnik and Starczewski (1995), and Kurnik, Starczewski and Przybyłowicz (1997).

4. Concluding remarks

As a result of the carried out numerical simulations it has been shown that journal bearing systems can exhibit irregular and chaotic motion. Occurrence of chaotic vibration depends on numerous parameters which characterise the structure and the working conditions together with external factors (excitations) as well. Even in journal bearings of increased stability (multi-lobe bearings) such a chaotic response of the rotor can also appear. It is especially dangerous since cannot be controlled. The problem of chaos in journal bearing systems still remains a great challenge for scientists and engineers, and still waits their acceptation.

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