Математички Институт САНУ
Кнеза Михаила 36
11 000 Београд
Србија

Директору Математичког института САНУ
Проф. др Зорану Огњановићу
Научном већу Математичког института САНУ
Академику Проф. др Драгошу Цветковићу

Извештај

са учешћа на симпозијуму

IUTAM SYMPOSIUM
'EXPLOITING NONLINEAR DYNAMICS FOR ENGINEERING SYSTEMS'
NOVI SAD, SERBIA, 15 - 19 JULY 2018

Поштовани,

У периоду од 15-19.07.2018. године учествовала сам у раду симпозијума "ENOLIDES 2018 – IUTAM Symposium „Exploiting nonlinear dynamics for engineering systems“ у организацији: IUTAM (International Union of Theoretical and Applied Mechanics) и „Faculty of Thechnical Science, Novi Sad“. Симпозијум је одржан на Универзитету у Новом Саду и Техничком факултету у Новом Саду.

У оквиру симпозијума предавања су била организована у само једној сесији, којој су присуствовали сви регистровани учесници. Моје излагање под насловом

„Nonlinear dynamics as a tool in selection of working conditions for radial ball bearing”

било је на програму последњег дана симпозијума, али је и поред тога било веома посећено. Излагала сам резултате који су део заједничких истраживања са колегама Дејаном Момчиловићем, Радивојем Митровићем, Наташом Солдат и Николом Нешићем и који су део истраживања у оквиру теме докторске дисертације докторанта Наташе Солдат. Након излагања, имала сам прилуку да одговорим на постављена питања колега и на основу сличних интересовања успоставим нове контакте за будућу сарадњу.

На Симпозијуму је било укупно око 50 излагања, од којих је било само неколико радова из Србије, већи број учесника из Италије , као и из Пољске, Грчке, Израела, Бразила и многих других земаља. У оквиру Симпозијума одржана су четири пленарна предавања и четири предавања посвећена угледним и успешним ствараоцима у овој области. Сва предавања су била веома посећена, а организација овог Симпозијума је била веома успешна испуњавајући све захтеве прописане правилима IUTAM-a (International Union of Theoretical and Applied Mechanics).

Поред радног дела програма, симпозијум је садржао и веома богат и одлично осмишљен друштвени део, са приликама за неформалне разговоре, успостављање нових контаката и идеја за будућа заједничка истраживања.

Изложени радови објављени су у штампаној форми као апстракти, а очекује се и штампање проширених радова у специјалном броју „The IUTAM Bookseries“ који штампа Springer.

У прилогу Извештаја достављам: Копију Позивног писма о прихватању рада за усмено излагање, Копију Сертификата о учешћу на Симпозијуму, Копију првих страна Књиге апстраката, Копију објављеног апстракта и неколико фотографија.

С поштовањем,

У Београду, 29.08.2018.

др Ивана Атанасовска,
виши научни сарадник

Прилози:

ENOLIDES

IUTAM SYMPOSIUM

NOVI SAD, SERBIA
15 – 19 JULY 2018

23 March 2018

Dear Ivana Atanasovska,

We are pleased to invite you to attend the IUTAM Sympoisum '**Exploiting Nonlinear Dynamics for Engineering Systems**' **ENOLIDES 2018**

http://enolides.ftn.uns.ac.rs/

which will be held at the Faculty of Technical Sciences, University of Novi Sad, Serbia from 15 to 19 July 2018, and present your work entitled:

NONLINEAR DYNAMICS AS A TOOL IN SELECTION OF WORKING CONDITIONS FOR RADIAL BALL BEARING,
jointly done with D. Momčilović, R. Mitrović, N. Soldat and N.Nešić.

For further information or assistance, please contact the organizers via e-mail enolides2018@uns.ac.rs or by phone +381 64 23 69 789 (Ivana Kovacic).

We look forward to meeting you in Novi Sad in July 2018.

With best wishes,

Ivana Kovacic, Chair of ENOLIDES and Stefano Lenci, Co-Chair of ENOLIDES

Exploiting Nonlinear Dynamics for Engineering Systems' ENOLIDES 2018

IUTAM SYMPOSIUM

ENOLIDES

NOVI SAD, SERBIA
15 – 19 JULY 2018

CERTIFICATE OF ATTENDANCE

This is to certify that

Ivana Atanasovska

attended the IUTAM Symposium

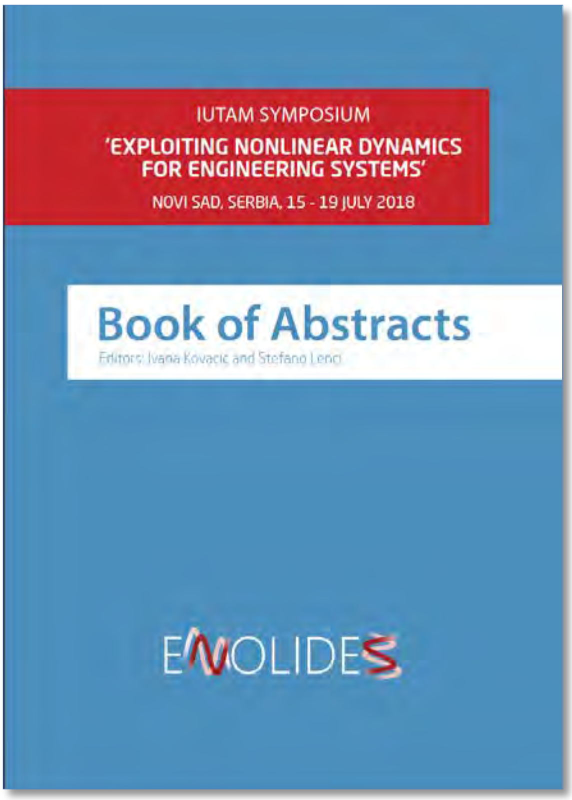
'Exploiting Nonlinear Dynamics for Engineering Systems' ENOLIDES 2018

held in Novi Sad, Serbia from 15 to 19 July 2018.

Chairperson of ENOLIDES:
Professor Ivana Kovacic

Co-Chair of ENOLIDES:
Professor Stefano Lenci

'Exploiting Nonlinear Dynamics for Engineering Systems' ENOLIDES 2018

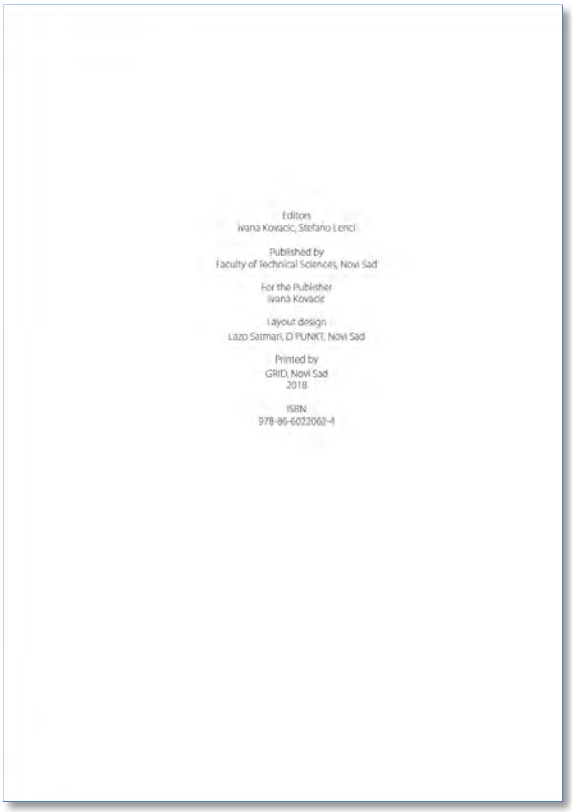


IUTAM SYMPOSIUM
'EXPLOITING NONLINEAR DYNAMICS FOR ENGINEERING SYSTEMS'
NOVI SAD, SERBIA, 15 - 19 JULY 2018

Book of Abstracts

Editors: Ivana Kovacic and Stefano Lenci

ENOLIDES



Editors
Ivana Kovacic, Stefano Lenci

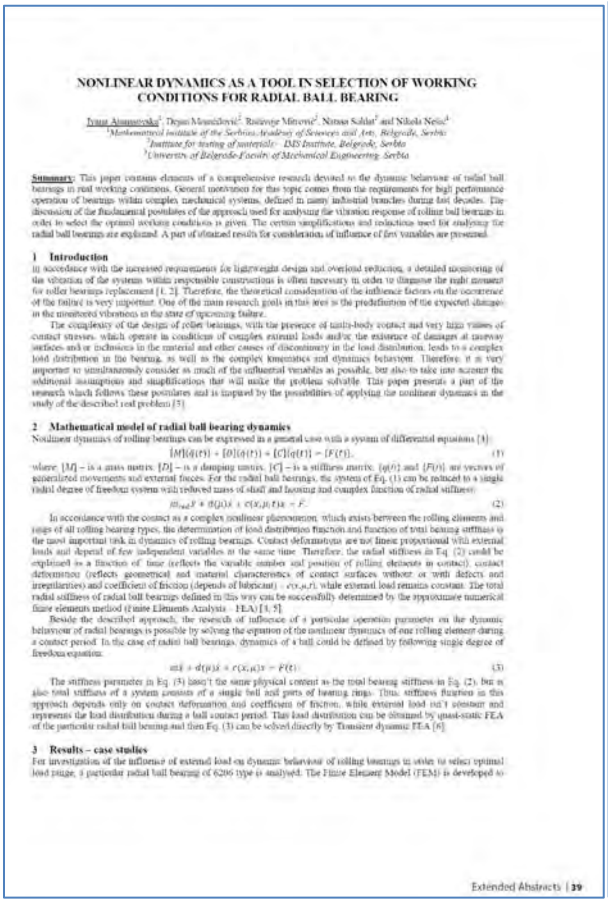
Published by
Faculty of Technical Sciences, Novi Sad

For the Publisher
Ivana Kovacic

Layout design
Lazo Satmari, D PUNKT, Novi Sad

Printed by
GRID, Novi Sad
2018

ISBN
978-86-6022062-4



NONLINEAR DYNAMICS AS A TOOL IN SELECTION OF WORKING CONDITIONS FOR RADIAL BALL BEARING

Ivana Atanasovska[1], Dejan Momčilović[2], Radivoje Mitrović[3], Natasa Soldat[3] and Nikola Nešić[3]
[1]Mathematical Institute of the Serbian Academy of Sciences and Arts, Belgrade, Serbia
[2]Institute for testing of materials – IMS Institute, Belgrade, Serbia
[3]University of Belgrade-Faculty of Mechanical Engineering, Serbia

Summary: This paper contains elements of a comprehensive research devoted to the dynamic behaviour of radial ball bearings in real working conditions. General motivation for this topic comes from the requirements for high performance operation of bearings within complex mechanical systems, defined in many industrial branches during last decades. The discussion of the fundamental postulates of the approach used for analysing the vibration response of rolling ball bearings in order to select the optimal working conditions is given. The certain simplifications and reductions used for analysing the radial ball bearings are explained. A part of obtained results for consideration of influence of few variables are presented.

1 Introduction

In accordance with the increased requirements for lightweight design and overload reduction, a detailed monitoring of the vibration of the systems within responsible constructions is often necessary in order to diagnose the right moment for roller bearings replacement [1, 2]. Therefore, the theoretical consideration of the influence factors on the occurrence of the failure is very important. One of the main research goals in this area is the predefinition of the expected damages in the monitored vibrations in the state of upcoming failure.

The complexity of the design of roller bearings, with the presence of multi-body contact and very high values of contact stresses, which operate in conditions of complex external loads and/or the existence of damages at raceway surfaces and/or inclusions in the material and other causes of discontinuity in the load distribution, leads to a complex load distribution in the bearing, as well as the complex kinematics and dynamics behaviour. Therefore, it is very important to simultaneously consider as much of the influential variables as possible, but also to take into account the additional assumptions and simplifications that will make the problem solvable. This paper presents a part of the research which follows these postulates and is inspired by the possibilities of applying the nonlinear dynamics in the study of the described real problem [3].

2 Mathematical model of radial ball bearing dynamics

Nonlinear dynamics of rolling bearings can be expressed in a general case with a system of differential equations [4]:

$$[M]\{\ddot{q}(t)\} + [D]\{\dot{q}(t)\} + [C]\{q(t)\} = \{F(t)\}, \quad (1)$$

where: $[M]$ – is a mass matrix, $[D]$ – is a damping matrix, $[C]$ – is a stiffness matrix, $\{q(t)\}$ and $\{F(t)\}$ are vectors of generalized movements and external forces. For the radial ball bearings, the system of Eq. (1) can be reduced to a single radial degree of freedom system with reduced mass of shaft and housing and complex function of radial stiffness:

$$m_{red}\ddot{x} + d(\mu)\dot{x} + c(x,\mu,t)x = F. \quad (2)$$

In accordance with the contact as a complex nonlinear phenomenon, which exists between the rolling elements and rings of all rolling bearing types, the determination of load distribution function and function of total bearing stiffness is the most important task in dynamics of rolling bearings. Contact deformations are not linear proportional with external loads and depend of few independent variables at the same time. Therefore, the radial stiffness in Eq. (2) could be explained as a function of: time (reflects the variable number and position of rolling elements in contact), contact deformation (reflects geometrical and material characteristics of contact surfaces without or with defects and irregularities) and coefficient of friction (depends of lubricant) – $c(x,\mu,t)$, while external load remains constant. The total radial stiffness of radial ball bearings defined in this way can be successfully determined by the approximate numerical finite elements method (Finite Elements Analysis – FEA) [3, 5].

Beside the described approach, the research of influence of a particular operation parameter on the dynamic behaviour of radial bearings is possible by solving the equation of the nonlinear dynamics of one rolling element during a contact period. In the case of radial ball bearings, dynamics of a ball could be defined by following single degree of freedom equation:

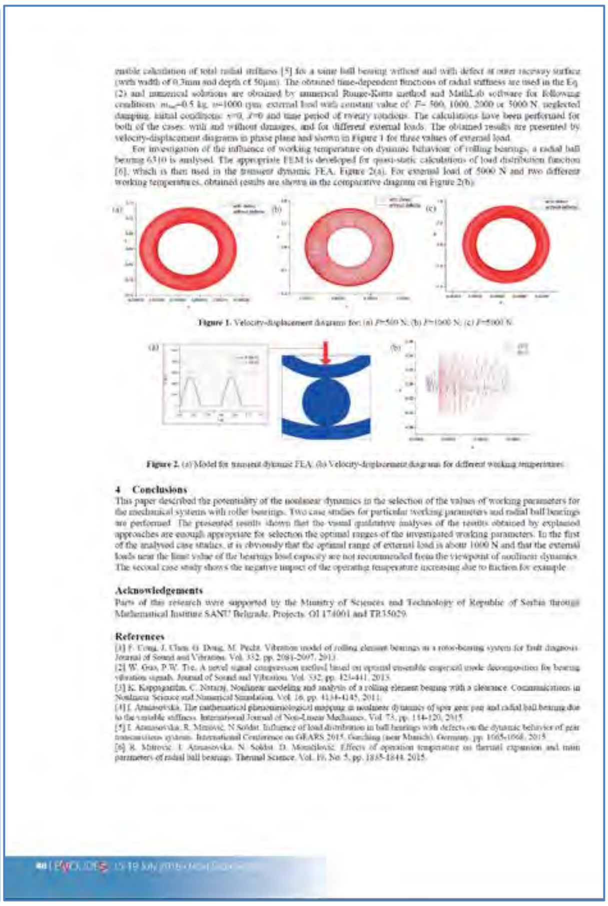
$$m\ddot{x} + d(\mu)\dot{x} + c(x,\mu)x = F(t). \quad (3)$$

The stiffness parameter in Eq. (3) hasn't the same physical content as the total bearing stiffness in Eq. (2), but is also total stiffness of a system consists of a single ball and parts of bearing rings. Thus, stiffness function in this approach depends only on contact deformation and coefficient of friction, while external load isn't constant and represents the load distribution during a ball contact period. This load distribution can be obtained by quasi-static FEA of the particular radial ball bearing and then Eq. (3) can be solved directly by Transient dynamic FEA [6].

3 Results – case studies

For investigation of the influence of external load on dynamic behaviour of rolling bearings in order to select optimal load range, a particular radial ball bearing of 6206 type is analysed. The Finite Element Model (FEM) is developed to

Extended Abstracts | 39



enable calculation of total radial stiffness [5] for a same ball bearing without and with defect at outer raceway surface (with width of 0.3mm and depth of 50μm). The obtained time-dependent functions of radial stiffness are used in the Eq. (2) and numerical solutions are obtained by numerical Runge-Kutta method and MathLab software for following conditions: m_{red}=0.5 kg, n=1000 rpm, external load with constant value of: F= 500, 1000, 2000 or 5000 N, neglected damping, initial conditions: x=0, ẋ=0 and time period of twenty rotations. The calculations have been performed for both of the cases: with and without damages, and for different external loads. The obtained results are presented by velocity-displacement diagrams in phase plane and shown in Figure 1 for three values of external load.

For investigation of the influence of working temperature on dynamic behaviour of rolling bearings, a radial ball bearing 6310 is analysed. The appropriate FEM is developed for quasi-static calculations of load distribution function [6], which is then used in the transient dynamic FEA, Figure 2(a). For external load of 5000 N and two different working temperatures, obtained results are shown in the comparative diagram on Figure 2(b).

Figure 1. Velocity-displacement diagrams for: (a) F=500 N; (b) F=1000 N; (c) F=5000 N.

Figure 2. (a) Model for transient dynamic FEA; (b) Velocity-displacement diagrams for different working temperatures.

4 Conclusions

This paper described the potentiality of the nonlinear dynamics in the selection of the values of working parameters for the mechanical systems with roller bearings. Two case studies for particular working parameters and radial ball bearings are performed. The presented results shown that the visual qualitative analyses of the results obtained by explained approaches are enough appropriate for selection the optimal ranges of the investigated working parameters. In the first of the analysed case studies, it is obviously that the optimal range of external load is about 1000 N and that the external loads near the limit value of the bearings load capacity are not recommended from the viewpoint of nonlinear dynamics. The second case study shows the negative impact of the operating temperature increasing due to friction for example.

Acknowledgements

Parts of this research were supported by the Ministry of Sciences and Technology of Republic of Serbia through Mathematical Institute SANU Belgrade, Projects: OI 174001 and TR35029.

References

[1] F. Cong, J. Chen, G. Dong, M. Pecht, Vibration model of rolling element bearings in a rotor-bearing system for fault diagnosis, Journal of Sound and Vibration, Vol. 332, pp. 2081-2097, 2013.
[2] W. Guo, P.W. Tse, A novel signal compression method based on optimal ensemble empirical mode decomposition for bearing vibration signals, Journal of Sound and Vibration, Vol. 332, pp. 423-441, 2013.
[3] K. Kappaganthu, C. Nataraj, Nonlinear modeling and analysis of a rolling element bearing with a clearance, Communications in Nonlinear Science and Numerical Simulation, Vol. 16, pp. 4134-4145, 2011.
[4] I. Atanasovska, The mathematical phenomenological mapping in nonlinear dynamics of spur gear pair and radial ball bearing due to the variable stiffness, International Journal of Non-Linear Mechanics, Vol. 73, pp. 114-120, 2015.
[5] I. Atanasovska, R. Mitrović, N Soldat, Influence of load distribution in ball bearings with defects on the dynamic behavior of gear transmissions systems, International Conference on GEARS 2015, Garching (near Munich), Germany, pp. 1065-1068, 2015.
[6] R. Mitrović, I. Atanasovska, N. Soldat, D. Momčilović, Effects of operation temperature on thermal expansion and main parameters of radial ball bearings, Thermal Science, Vol. 19, No 5, pp. 1835-1844, 2015.

40 | ENOLIDES 15-19 July 2018 • Novi Sad

Прилог: Фотографије са Симпозијума

Са отварања Симпозијума:

Предавања по позиву:

Са предавања:

Обилазак Сремских Карловаца и Петроварадина:

Са затварања Симпозијума: