International Conference on Engineering Vibrations
Aberdeen, Scotland, 18 – 21 August 2020

NONLINEAR ANALYSIS OF REGENERATIVE AND FRICTIONAL CUTTING DYNAMICS BASED ON A NEW MODEL

Yao Yan[1], Jian Xu[2,3], Marian Wiercigroch[4]
[1] *School of Aeronautics and Astronautics, University of Electronic Science and Technology of China, Chengdu, 611731, China, y.yan@uestc.edu.cn*
[2] *Shanghai Institute of Intelligent Science and Technology, Tongji University, Shanghai, 200092, China, xujian@tongji.edu.cn*
[3] *School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai 200092, China*
[4] *Centre for Applied Dynamics Research, School of Engineering, Fraser Noble Building, King's College, University of Aberdeen, Aberdeen, AB24 3UE Scotland, UK, m.wiercigroch@abdn.ac.uk*

ABSTRACT

This study introduces a new simple one degree-of-freedom (DOF) model involving time-delayed regenerative effect in chip formation, Stribeck effect in frictional velocity, and process damping in tool's flank face, which yields a better prediction of linear cutting stability in the low-velocity zone [1]. Further investigation shows that a small coefficient of static friction and a large Stribeck velocity improve the cutting stability in low- and intermediate-velocity zones, and large shear and rake angles always enhance the cutting stability [2]. Next perturbation analysis on the cutting stability boundaries shows a co-existence of stationary cutting and chatter in the linearly stable region. Comparing this analytical estimation with numerical simulations reveals the possibility of underestimation of the UZs due to the large-amplitude frictional chatter. Global bifurcation analysis based on numerical simulations yields various complex cutting dynamics including multiple stability, regenerative chatter with loss of tool-workpiece contact and stick-slip frictional vibration. Finally, the cutting safety in the UZs is estimated based on basin stability estimation, with the time-delayed initial conditions approximated by Fourier series and Monte Carlo principle [3]. It is found that the large-amplitude frictional chatter hardly influences the UZs from stochastic viewpoint, and a fine workpiece surface and a static tool can drive the cutting dynamic towards orbits with lower vibration strength.

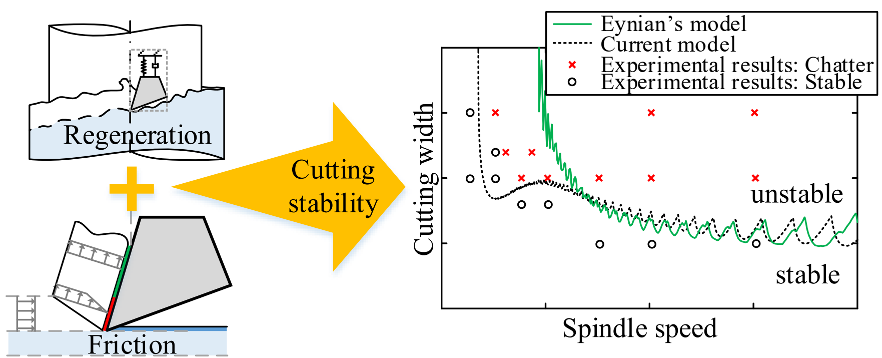

Figure 1: Combining regeneration and friction yields a better stability diagram compared with Eynian's model [1]

Keywords: Time delay, Regenerative cutting, Friction, Process damping, Unsafe cutting

[1] Altintas, Y., Eynian, M. and Onozuka, H. 2008 Identification of dynamic cutting force coefficients and chatter stability with process damping. *CIRP Annals* 57(1), 371-374.

[2] Yan, Y., Xu, J. and Wiercigroch, M. 2019 Modelling of regenerative and frictional cutting dynamics. *International Journal of Mechanical Sciences* 156, 86–93.

[3] Yan, Y., Xu, J. and Wiercigroch, M. 2019 Estimation and improvement of cutting safety. *Nonlinear Dynamics* 98, 2975–2988.

INTERFACE CRACKS UNDER HARMONIC HEAR: EFFECTS OF CONTACT AND FRICTION

Oleksandr Menshykov[1], Vasyl Menshykov[2], Igor A. Guz[3]
[1]*School of Engineering, University of Aberdeen, AB243UE, Scotland, UK,* o.menshykov@abdn.ac.uk
[2]*National Aerospace University – KhAI, Chkalova St, 17, Kharkiv 61000, Ukraine,* v.menshykov@khai.edu.ua
[3]*School of Engineering, University of Aberdeen, AB243UE, Scotland, UK,* i.guz@abdn.ac.uk

ABSTRACT

The linear crack between two dissimilar elastic isotropic half-spaces under normal harmonic shear loading is considered. The system of boundary integral equations for displacements and tractions at the interface is derived from the dynamic Somigliana identity in the frequency domain [1]. To take the crack faces' contact interaction into account we assume that the contact satisfies the Signorini normal contact constraints and the Coulomb friction law. The components of the solution are represented by the trigonometric Fourier series. The problem is solved numerically using the iterative process – the solution changes until the distribution of the displacements and tractions satisfying the contact constraints is found [2]. The numerical convergence of the method with respect to the number of the Fourier coefficients and the mesh size is analysed for different frequencies of the loading. The effects of material properties and values of the friction coefficient on the distribution of stress intensity factors (opening and shear modes) are presented and discussed. Special attention is paid to the length of the contact zone and the results are compared with the classical model solutions obtained for the static problems with friction [3]. In the future, the approach might be applied to three-dimensional fracture mechanics problems for layered cracked materials under dynamic loading with friction.

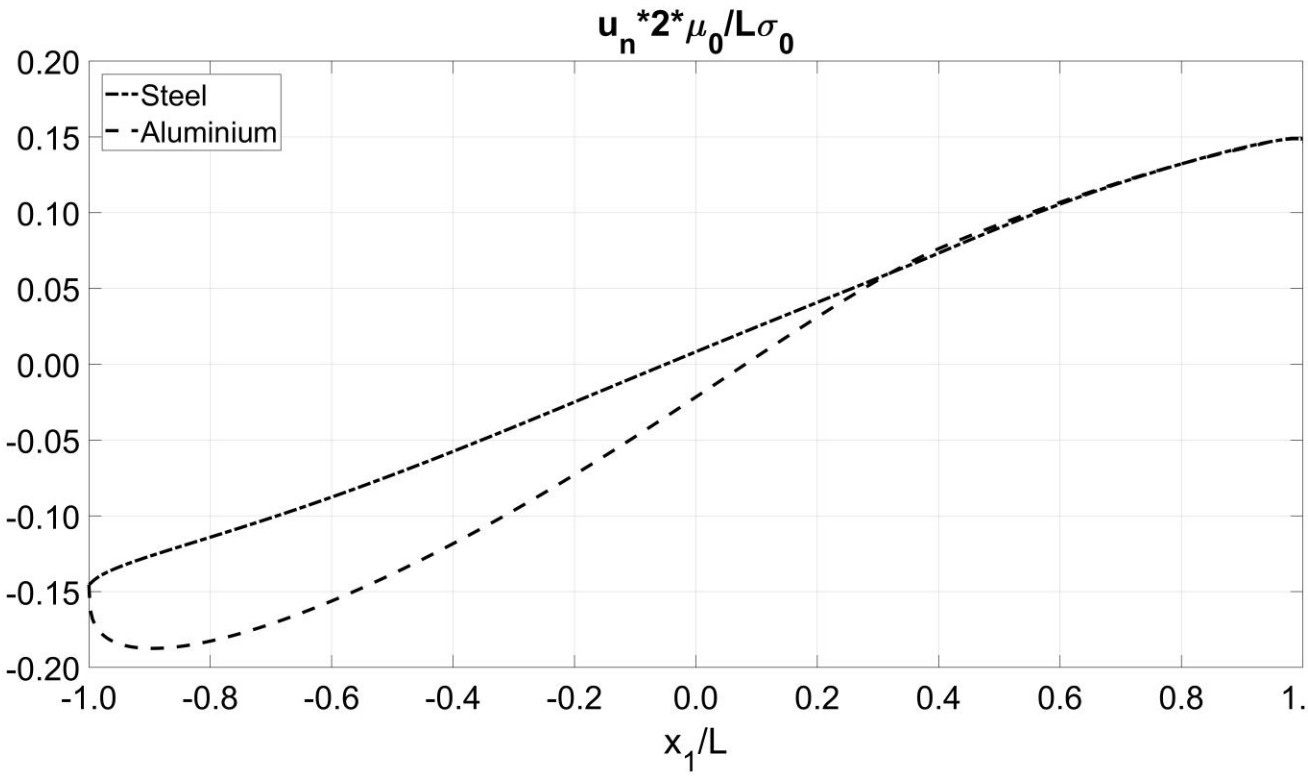

Figure 1: Max normal displacements of Steel-Aluminium faces, dimensionless wave number 1.0, friction coefficient 1.0

Keywords: Interface Crack, Boundary Integrals, Contact Zone, Stress Intensity Factors.

[1] Menshykov, O. V., Guz, I. A. and Menshykov, V. A. 2008 Boundary integral equations in elastodynamics of interface cracks. *Philosophical Transactions of the Royal Society A* **366(1871)**, 1835–1839.
[2] Menshykova, M., Menshykov, O. and Guz, I. A. 2011 An iterative BEM for the dynamic analysis of interface crack contact problems. *Engineering Analysis with Boundary Elements* **35**, 735–749.
[3] Comninou, M. and Dundurs, J. 1980 Effect of friction on the interface crack loaded in shear. *Journal of Elasticity* **10**, 203–212.

SYNCHRONY IN FRICTIONAL OSCILLATORS

Danylo Pikunov and Andrzej Stefanski
Division of Dynamics, Lodz University of Technology, ul. Stefanowskiego 1/15 Lodz, Poland; steve@p.lodz.pl

ABSTRACT

The presented article is dedicated to the numerical investigations of dry friction processes. The problem under consideration is a specific mapping of the system's attractor on the friction force characteristic − reflection effect [1]. Such reflection is particularly evident when the motion of the system is irregular. Thus, it can be concluded that the classical formula for friction $F_T = f(v)$ is replaced by the relatio

$$F_T = \Psi(\mathbf{x}), \quad (1)$$

where $\mathbf{x}$ is a state vector of the system.

The correlation given by Eq. (1) can be treated as a state of generalized synchrony between the friction force and the oscillator's response [2]. The generalized synchronization state is stable if so-called conditional Lyapunov exponents (LEs) are negative. Hence, the spectrum of LEs which also takes into account the dynamic friction model given by differential equations, can be an useful criterion to answer the question about the nature of the correlation between the friction force and the oscillator's response. A positive Lyapunov exponent related to friction force may indicate a lack of such correlation. The existence of reflection effect in the case of LuGre and the modified LuGre dynamic dry friction models by means of the LEs estimation method for non-smooth systems [3] has been confirmed [4].

In this paper we are about to analyze the frictional oscillator model which accounts the normal degree of freedom in friction. The mentioned model has been introduced basing on the idea published by Berger [15] which assumes main oscillator and a number of microscopic bristles attached to it and deflecting in both the tangential and the normal directions. The mathematical model of the studied dynamical system has been derived and then simulated for different values of the control parameter. It has been revealed that the proposed frictional system tends to show the reflection effect between the friction and the oscillator for certain values of the frictional surface roughness wavelength. However, hyperchaotic behavior of the oscillator leads to the destabilization of the studied synchronization effect in hyperchaotic regime, despite the observed phase correlation of the oscillator–slider system. On the other hand, irregular jumps of friction force can be also observed in case of regular (quasi-periodic and synchronous) vibrations of the oscillator, slider and normal pressure force (see Figs 3.4a-c). The phase synchronization and quasi-periodicity can be seen more clearly from the long term time series. Therefore, the answer for the question if the character of disorder between the friction force and response of the oscillator has a deterministic nature is ambiguous.

Keywords: friction maodelling, stick-slip vibration, generalized synchronization.

[1] Wojewoda, J., Stefański, A., Wiercigroch, M. & Kapitaniak, T. (2008). Hysteretic effects of dry friction: modelling and experimental studies. Philosophical Transactions of the Royal Society of London A, 366, pp. 747-765.
[2] Rulkov, F., Sushchik, M. M., Tsimring, L. S., Abarbanel, H. D. I. (1995). Generalized synchronization of chaos in directionally coupled systems, *Phys. Rev.* E, 51, pp. 980–984.
[3] Balcerzak, M., Dabrowski, A., Stefański, A., & Wojewoda, J. (2018) Spectrum of Lyapunov exponents in non-smooth systems evaluated using orthogonal perturbation vectors. In MATEC Web of Conferences, EDP Sciences. 148, 10003.
[4] Pikunov, D., & Stefański, A. (2019). Numerical analysis of the friction-induced oscillator of Duffing's type with modified LuGre friction model. Journal of Sound and Vibration, 440, 23-33.

GEOMETRIC JUDDER IN AUTOMOTIVE MULTI-DISK CLUTCHES: STOCHASTIC SIMULATION APPROACH

Georg Jehle[1], Achim Seifermann[2]
[1] *Schaeffler Automotive Buehl GmbH & Co. KG, Industriestr. 3, Bühl, Germany, georg.jehle@schaeffler.com*
[2] *achim.seifermann@schaeffler.com*

ABSTRACT

Modern automotive drivetrain concepts, driven by combustion engine or by hybrid concepts, necessitate the use of clutches meeting novel demands. In order to reach required torque values, a desired shifting performance and appropriate system cooling possibilities, plate clutch systems have proven to be a good solution. This technology basically consists of plate carriers connected with engine side and gearbox side, where friction plates and separator plates are hinged (Fig. 1). By normal contact of the plates and due to friction, the engine torque is transmitted to the gearbox.

Because of production tolerances in surfaces as well as inhomogeneous material behavior, the transmitted sliding torque of a clutch is usually non-uniform: A mean sliding torque is superimposed by vibrations at frequencies being mainly rotational slip speed multiples. This phenomenon is called geometric judder. It is well-known and understood from brakes and dry manual clutch systems [1-3] incorporating only one or two contact surfaces.

The high number of contacts (plate-plate contacts, plates-plate carrier contacts) with local deviations of contact properties as well as non-linear properties of the tribological system make the character of judder measurements random [4]. Influencing factors range from surface quality of single plates as well as relations between surfaces within the friction package, local material properties, oil distribution, and initial configurations of mechanical components.

In order to reach a better understanding in how to decrease judder intensity in production series of plate clutches, a stochastic MBS model is set up. It includes plates in plate carriers, contact elements with non-flat surface as well as a tooth contacts with backlash (Fig. 2). The goals are the reproduction of experimental judder values in a statistical sense, the verification of known countermeasures, and above all, correlations between quality parameters and judder values at different slip multiples. The situation that quality parameters (surface quality, tilting misalignment, friction coefficient deviation, …) as well as initial configurations of plates in plate carriers can't be controlled or even measured is captured by the application of Monte-Carlo simulations. With the help of this approach, correlations are found between parameters and judder values, the influences are quantified, and finally countermeasures can be generated.

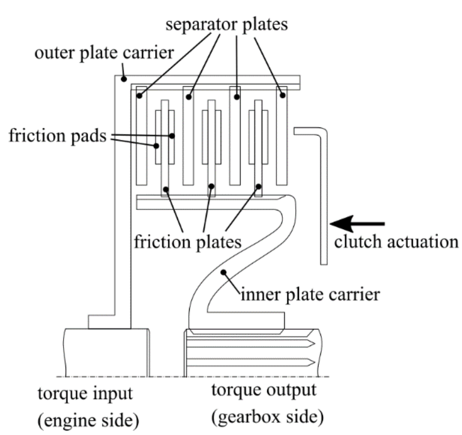

Figure 1: Design of a plate clutch

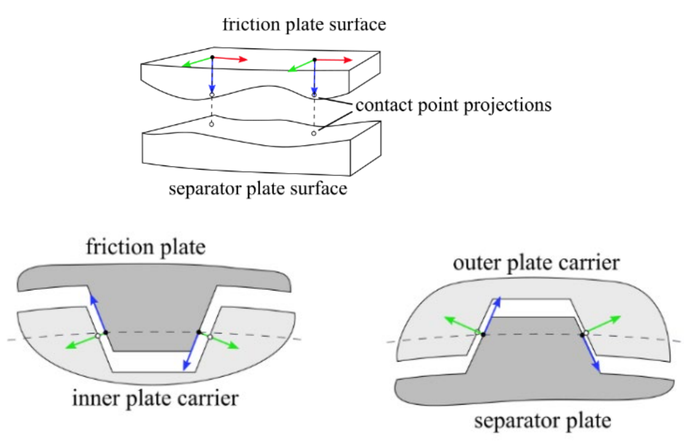

Figure 2: Model details: non-flat plate contacts and plate-plate carrier contacts

Keywords: Geometric judder, friction induced vibrations, automotive transmission.

[1]Jacobsson, H. 2003 Apects of disc brake judder. *Proc. Instn Mech. Engrs* 217, 419–430.

[2]Albers, A., Herbst, D. 1998 Rupfen - Ursachen und Abhilfen. *LuK for the best connection in comfort and economy - 6. LuK-Kolloquium*, 23–46.

[3]Hausner, M., Häßler, M. 2012 Clutch Disc with Frequency Damper to Prevent Judder Vibrations. *M. ATZ Worldw* 114, 42–47.

[4]Frisch, H. 2017 *Untersuchung der Einflussgrößen auf die Gleichförmigkeit der Drehmomentübertragung einer nasslaufenden Doppelkupplung*. PhD thesis, Universität Kassel.

Nonlinear dynamics of rotor whirling within an asymmetrically supported snubber ring

Heba El-Mongy[1,2], Tamer El-Sayed[1,2], Vahid Vaziri[1], Marian Wiercigroch[1]
[1] *Centre for Applied Dynamics Research, School of Engineering, University of Aberdeen, Aberdeen, UK*
[2] *Department of Mechanical Design, Faculty of Engineering, Mataria, Helwan University, Cairo, Egypt*

ABSTRACT

Rotor-stator rubbing is one of the serious malfunctions that commonly occur in rotating machinery and mostly causes severe damage. In this paper, the nonlinear dynamics of a rotor whirling within a snubber ring are explored using numerical simulations considering full stiffness asymmetry of the snubber ring support. A two degrees of freedom model is used to investigate rubbing interactions between the rotor and the snubber ring where a linear elastic contact model is assumed. The static offset between the centers of the rotor and the snubber ring is also included as given in [1, 2]. The dynamic behavior of a rubbing system is known to exhibit a strong non-linearity due to switching between contact and non-contact modes [3]. Hence, the nonlinear rotor response is examined to study the influence of the stator asymmetry using time waveforms, frequency spectra, rotor orbits and bifurcation diagrams. Moreover, the effects of varying system parameters such as unbalance mass, rotational speed, damping ratio and static eccentricity in presence of stator asymmetry are studied in detail. The rub response is shown to be highly sensitive to changing system parameters. It is found that the stator asymmetry greatly affects the system response causing significant changes even for small values of asymmetry. However, the effect of direct stiffness asymmetry is more pronounced than the cross-coupling stiffness effect. Periodic, quasi-periodic and chaotic responses are observed for the sets of parameters considered here. Also, regions of periodic response with coexisting chaos are detected. The results show very rich dynamics such as period doubling, period halving and jump bifurcations. The observed routes to chaos have been quasi-periodic and period doubling routes. The results obtained contribute towards better understanding of the nonlinear phenomena associated with rotor-stator rubbing and help exploring unique features of the rubbing fault which may be useful for diagnostic purposes.

Keywords: Rotor-stator rubbing, Nonlinear dynamics, Snubber ring, Stator stiffness asymmetry

[1] E.V. Karpenko, M. Wiercigroch, M.P. Cartmell, Regular and chaotic dynamics of a discontinuously nonlinear rotor system, Chaos, Solitons and Fractals, 13 (2002) 1231-1242.

[2] E.V. Karpenko, M. Wiercigroch, E.E. Pavlovskaia, M.P. Cartmell, Piecewise approximate analytical solutions for a Jeffcott rotor with a snubber ring, International Journal of Mechanical Sciences, 44 (2002) 475-488.

[3] E.E. Pavlovskaia, E. Karpenko, M. Wiercigroch, Non-linear dynamic interactions of a Jeffcott rotor with preloaded snubber ring, Journal of Sound and Vibration, 276 (2004) 361-379.

International Conference on Engineering Vibrations
Aberdeen, Scotland, 18 – 21 August 2020

NONLINEAR DYNAMICS AND STABILITY ANALYSIS OF JOURNAL BEARING BASED ON SECOND ORDER STIFFNESS AND DAMPING PARAMETERS

Husein Sayed [1], Tamer A El-Sayed [2]
[1] *(Helwan University, Department of Mechanical Design, Faculty of Engineering, Mataria, Helwan University,*

P.O. Box 11718, Helmeiat-Elzaton, Cairo, Egypt, husseinsayed2008@yahoo.com)

[2] *(Aberdeen University, Scotland, tamer.el-sayed@abdn.ac.uk)*

ABSTRACT

Journal bearings are used in many engineering applications in the industry such as pump rotors, hydraulic turbocharger, crank shaft, etc. The modelling of the nonlinear dynamics and stability of rotors mounted on journal bearings is very crucial. This involves solving the Reynolds equation which governs the journal bearings at each time step which is time consuming. Alternatively, the linear and nonlinear bearing coefficients can be obtained and very limited work have been done in this area [1, 2]. Evaluating the bearing coefficients reduces the time required for the dynamic analysis of such bearings. In the current work, time dependent second order perturbation method is used to evaluate the journal bearings linear and nonlinear stiffness and damping parameters [3]. In addition, the present analysis considers using the second order approximation in obtaining the eccentricity and attitude angle perturbation. The linear and nonlinear stiffness and damping parameters are obtained for different operating conditions and for both grooved and ungrooved journal bearing. The results are compared with the published results and the results are found to be very close to the published ones. The journal bearing results are used to evaluate the response of rigid Jeffcott rotor using both nonlinear analysis and the analysis based on bearing coefficient. The stability analysis is used to obtain the critical speed and the hopf bifurcation theory is used to determine the stability of the limit cycle [4].

Keywords: Journal bearing, nonlinear stiffness and damping coefficient, nonlinear dynamics, stability analysis, limit cycles.

[1] M. Miraskari, F. Hemmati, M.S. Gadala, Nonlinear Dynamics of Flexible Rotors Supported on Journal Bearings—Part II: Numerical Bearing Model, Publisher, City, 2018.
[2] A. Chasalevris, Stability and Hopf bifurcations in rotor-bearing-foundation systems of turbines and generators, Publisher, City, 2020.
[3] W. Weimin, Y. Lihua, W. Tiejun, Y. Lie, Nonlinear dynamic coefficients prediction of journal bearings using partial derivative method, Publisher, City, 2012.
[4] B.D. Hassard, B. Hassard, N.D. Kazarinoff, Y.-H. Wan, Y.W. Wan, Theory and applications of Hopf bifurcation, CUP Archive, 1981.