LYAPUNOV EXPONENTS FOR NON-SMOOTH SYSTEMS VIA THE COMPUTATIONAL SUITE ABESPOL

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ABSTRACT

The calculation of the Lyapunov exponents for a system response allows for distinguishing between chaotic responses and non-chaotic ones whose transients take significant amount of time. This nonlinear dynamic technique is important for non-smooth systems which have still a lot of open questions. In the case where at least one Lyapunov exponent is positive, the system response is sensitive to initial conditions, that is, neighboring orbits go away from each other exponentially fast, in which case the response is defined as chaotic [2-5].

In the present work, the Matlab-based computational suite ABESPOL [1] have been developed further by adding a module to compute Lyapunov exponents for non-smooth systems. The piecewise linear system modelled with soft impacts that is shown in Figure 1 have been used to test the module. This system has served as a basic prototype to investigate new phenomena arising from impacts [6].

The newly created Lyapunov exponents module is a part of ABESPOL and interacts with the module of direct numerical integration. With this new module, the computations of Lyapunov exponents are done in a post-processing manner for each of the system responses computed during the construction of a bifurcation diagram. The responses obtained in these diagrams, as one of the control parameters is varied, include periodic and chaotic attractors. The external force amplitude and frequency were chosen as the control parameters for specific regions of parameters that exhibit a rich dynamic behaviour.

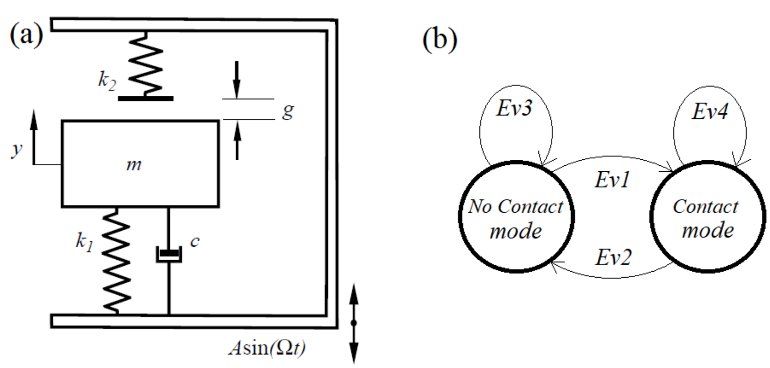

Figure 1: (a) Physical model of the considered oscillator and (b) the system elements that need to be defined in ABESPOL for running the simulations: operation modes, events functions and jump functions. Here for events *Ev1* and *Ev2* the jump function is the identity, whereas for event *Ev3* and *Ev4* that detect a Poincaré section the jump function resets the angular variable. Moreover, additional events such as grazing incidents can be defined.

Keywords: Non-smooth Systems, Impacts, Numerical Simulation, Bifurcation Analysis, Lyapunov Exponents

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LINEAR SYSTEMS INSPIRED MODIFIED INTEGRAL RESONANT CONTROLLER FOR SUPPRESSING STICK-SLIP OSCILLATIONS IN DRILL-STRINGS

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ABSTRACT

In oilfield drilling applications, drill-strings experience many different types of complex destructive dynamics that compromise the drilling procedure, causing significant financial losses. One of the most notable example is the 'stick-slip' oscillation, in which the drill-string undergoes violent starting and stopping motions, generating large accelerations that have the potential to cause major damage to the structure [1]. Consequently, it is of paramount importance to minimize, and where possible, eliminate these undesirable stick-slip oscillations. In this paper, the dynamics of a vertical drill-string and its bit-rock interaction are modeled as a 4-DOF structure paired with a multi-part friction model. This drill-string model can undergo three different co-existing behaviourial phases (attractors), namely; stick (no drilling), constant drilling (ideal) and stick-slip (destructive). Using this model, a region within the operational parameter-space where multiple co-existing attractors manifest, is first identified. Furthermore, a Modified Integral Resonant Controller (MIRC) [2], is proposed as a potential method to mitigate these unwanted stick-slip oscillations and its efficacy is demonstrated via extensive simulations - clearly demonstrating its capability in eliminating stick-slip and establish constant drilling over the parameter-space of interest.

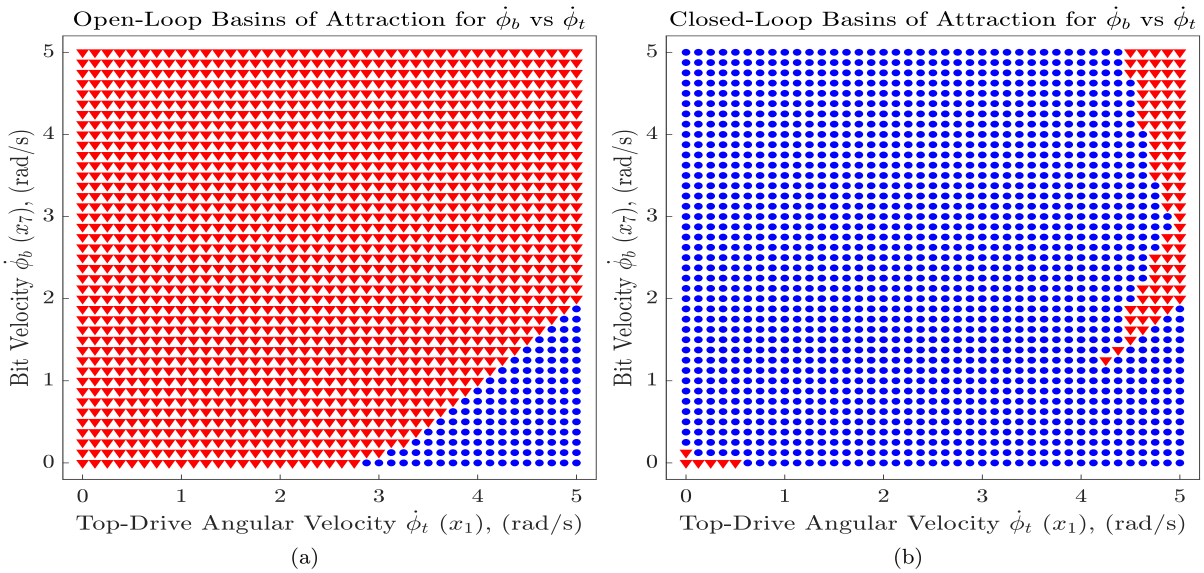

Figure 1: (a) Basins of attraction plot for the open-loop (uncontrolled system) clearly showing that the operational parameter-space is dominated by undesirable stick-slip dynamics (red triangles), while constant-velocity drilling (blue circles) occurs within a very limited set of parameters. (b) Basins of attraction plot for the MIRC-controlled closed-loop system shows that constant velocity drilling is established for almost all of the operational parameter-space considered.

Keywords: Drill-strings, stick-slip oscillations, closed-loop control

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SIMULATION OF A PENDULUM TUNED MASS DAMPER UNDER RANDOM EXCITATION

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ABSTRACT

Pendulum Tuned Mass Dampers (PTMD) are devices used for vibration dissipation. It uses the sway motion of a mass to counteract the vibrations of a structure. Yet, the coupled motion between the structure under excitation and the pendulum is complex and nonlinear. Furthermore, such devices can be simulated with deterministic inputs to determine their behaviour for harmonic excitation. For tall structures, wind and earthquakes can incorporate stochastic inputs to such systems. Therefore, a simulation of such systems in their fully nonlinear format subjected to realistic inputs is needed to better understand the capacities and properties of these damping devices. Similar devices such as the Coriolis-damped pendulum in [1] have been analysed but were linearised to minimise their complexity.
Common techniques struggle when dealing with nonlinear systems and stochastic/chaotic behaviour. The study presented here makes use of the theory of stochastic calculus [2] to produce simulations of a non-linearised PTMD system under stochastic excitation. These simulations were produced in MATLAB®.

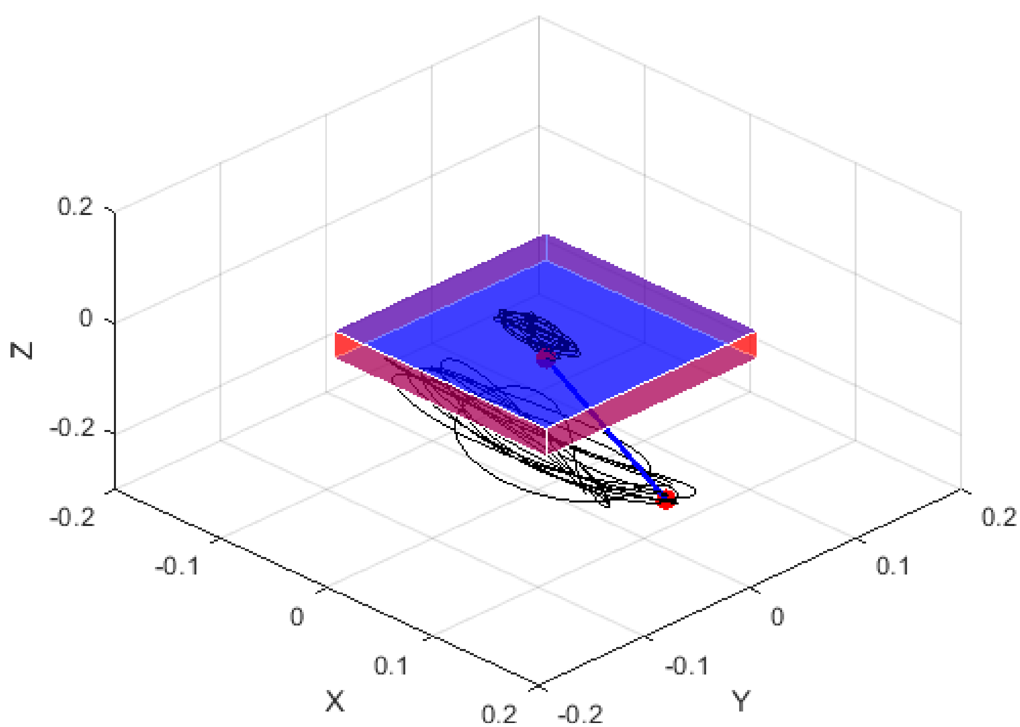

Figure 1: Captured video frame of a 3-D simulation of a PTMD attached to a simulated structure.

Keywords: Simulation, Stochastic Differential Equations, Vibrations

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INFLUENCE OF PRESSURE WAVES ON THE NEAR BOTTOMHOLE FORMATION ZONE PERMEABILITY

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ABSTRACT

A significant scientific effort has been devoted to the study of rock permeability changes depending on effective rock pressure. The main area of research in such works is the establishment of dependences of changes in rock permeability on increasing/decreasing effective rock pressure under steady-state conditions [1, 2]. However, as shown in [3], when wells are operated by sucker rod pumps, pumping out of the liquid occurs unevenly, as a result of which the pressure at the bottom of the well changes stepwise. Figure 1 presents a time history of changes in bottom-hole pressure during pumping periods in a well operating in two isolated objects. When pumping fluid from the lower *Formation 2* (see Fig. 2) in zones 1 (see Fig. 1), the pressure at the pump intake during its operation changes more intensively than while pumping from the *Formation 1* in zone 2. This is due to the damping of pressure surges by a liquid and gas column above the packer.

These pressure surges result in appearance of elastic pressure waves propagating along the bottom-hole zone of the formation and affecting its permeability. The paper presents the dependences of the influence of elastic pressure waves on the change in the permeability of the formation near bottom-hole zone based on filtration studies of core samples. The presented model of pore space deformation under the influence of elastic waves makes it possible to evaluate the change in permeability of the bottom-hole formation zone during well operation with rod pumps.

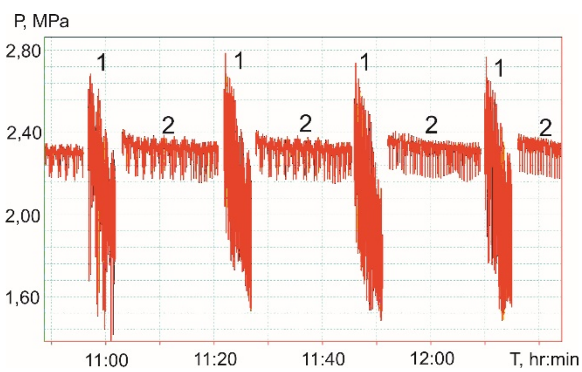

Figure 1. Time history of pressure during pumping.

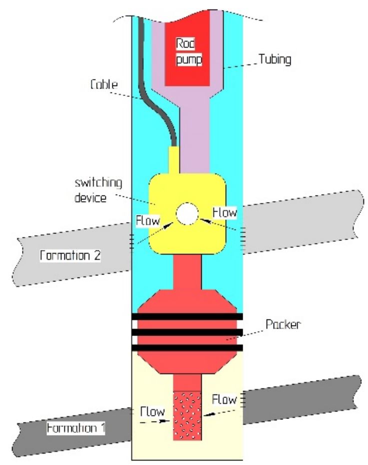

Figure 2. A sketch of pubbing scheme for simultaneous production.

Keywords: confining pressure, permeability, filtration test, core sample, pressure waves

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Dynamics and energy saving control of sucker-rod pumping systems

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ABSTRACT

The motor load torque of a typical pumping system employed in onshore oil-fields has a fluctuating 'double-hump' profile, which requires a motor with a substantially higher rating than the average load torque. In this work, we have developed a dynamical model of this electro-mechanical system. To reduce the load fluctuation and consequently lower the required motor rating and energy consumption, a real-time voltage and frequency optimization scheme (RTVFOS) is proposed [1]. It is demonstrated that the RTVFOS is capable of substantively decreasing the motor rating and delivering a significant energy savings. However, the scheme relies on a complex model of this electromechanical system, and it is computationally expensive. A closed-loop frequency control scheme (CLFCS) is further proposed with a rapid response and good robustness, and it allows to reduce the motor rating by further 30% of that required in the open-loop scheme [2].

Keywords: Sucker-rod pumping system, Dynamics, Energy saving, Frequency and voltage control, Electro-mechanical model

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ATTRACTORS OF ROTATING PENDULUMS

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ABSTRACT

Rotating pendulums are very useful in the harvesting of energy from sources such as water waves. Deployment in a wave flume by Lenci and Rega [1] showed that the range of frequencies, within which rotations could be sustained, was narrow. To increase the frequency range to sustain robust rotational attractors, a control strategy would be required. However, the energy input as part of a controller should be less than the amount of energy generated from rotations.

An experimental rig was constructed to test the case of periodic excitation. A solenoid was switched on and off at equal intervals of time. For the experimental rig shown in Figure 1 [2], a rotational attractor without a control input was possible, existing between a forcing frequency of 1.90 Hz and 2.70 Hz. In an alternative optimized configuration, the range of forcing frequencies was found to be between 1.60 Hz and 2.20 Hz. A mathematical model had also been derived to correlate predictions from direct numerical integration to experimental observation. Since many practical situations entail a stochastic forcing, the solenoid was switched on and off according to the distribution function of the Pierson-Moskowitz wave spectrum. For this forcing scenario, the pendulum is not inclined to rotate, and a control strategy was needed to keep the angular velocity above a threshold value. A bang-bang controller was implemented experimentally. Without control, it was possible to maintain rotational motion for up to $C_1 = 0.3$ in Pierson-Moskowitz wave spectrum noise, where C_1 is a multiplication factor corresponding to a level of noise. For $C_1 > 0.3$, a direct current permanent magnet motor effected a control torque as and when necessary. This was even possible for the case of $C_1 = 1.0$. The amount of generated energy was measured by a direct current motor used in reverse. The positive investment of energy to effect a control torque in relation to generated energy was confirmed for cases of $C_1 = 0.3$, 0.6 and 1.0.

For a third case whereby vertical oscillations of pivot were chaotic in nature, the spring assembly in the experimental rig was modified such that a discontinuity in stiffness characteristics was introduced to the system. Since the solenoid was switched on and off periodically, the irregular vertical pivot oscillations are expected to be chaotic in nature. It was possible to secure positive investments in energy for excitation frequencies of 2.20 Hz, 2.50 Hz and 2.60 Hz while securing a rotational attractor.

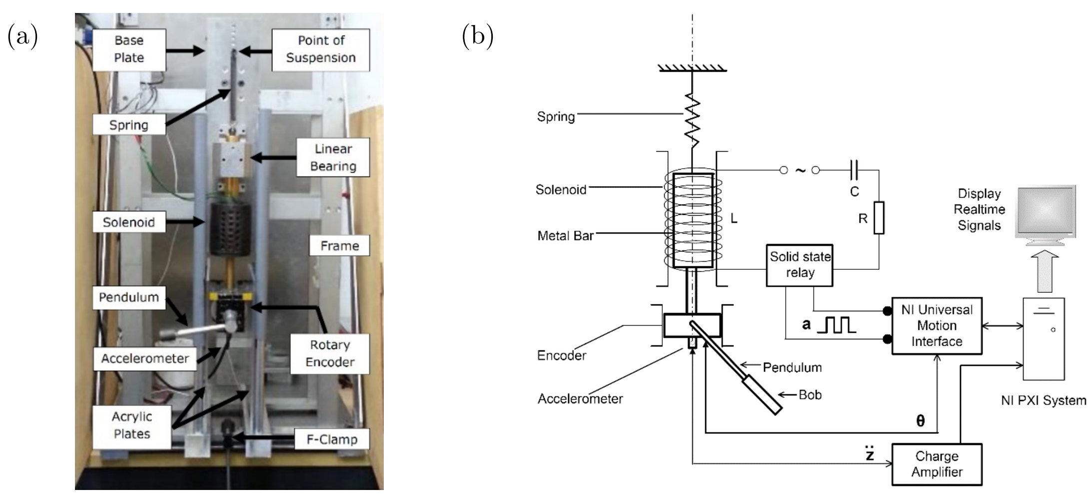

Figure 1: (a) Experimental rig in [2]. (b) Schematic of Figure 1(a)

Keywords: pendulums, energy harvesting

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MATHEMATICAL MODELLING OF FATIGUE RIG WITH CRACKED SPECIMEN

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ABSTRACT

Estimation of fatigue life of mechanical or structural components under cyclic and random loading is a key issue in the design of mechanical components in machinery or assessment of offshore structures for suitability of the service to ensure adequate fatigue life. A fatigue rig was designed and tested in the university of Aberdeen [1]. The rig was recently updated to accommodate experimental tests on tubular specimens with a range of sizes and other cross sections while monitoring the exact dynamic force applied to the specimen using newly designed load cells [2]. The crack initiation and propagation on tubular specimens with surface irregularities were investigated using alternating current potential difference (ACPD) method. The mathematical equations describing the rig behaviour with cracked specimens were explained by Foong et al [3].

A series of finite element (FE) analysis models were created to derive the nonlinear behaviour of a tubular cracked specimen. It was observed that the bending stiffness of the cracked specimens for the crack closing case is very similar to an uncracked specimen however, the cracked specimen bending stiffness was nonlinear and decreased with the growth in crack depth.

A nonlinear specimen stiffness curve was achieved by fitting to the FE results. The stiffness curve incorporated to the mathematical model of the rig. Using the ACPD data the specimen stiffness was redefined as function of time. The displacements, velocities and accelerations were derived by solving the mathematical model in time domain. The results of the mathematical model were compared against the measurements from experiment data acquisition. A parametric study was performed to calibrate the system parameters and investigate the rig sensitivity to the input variables.

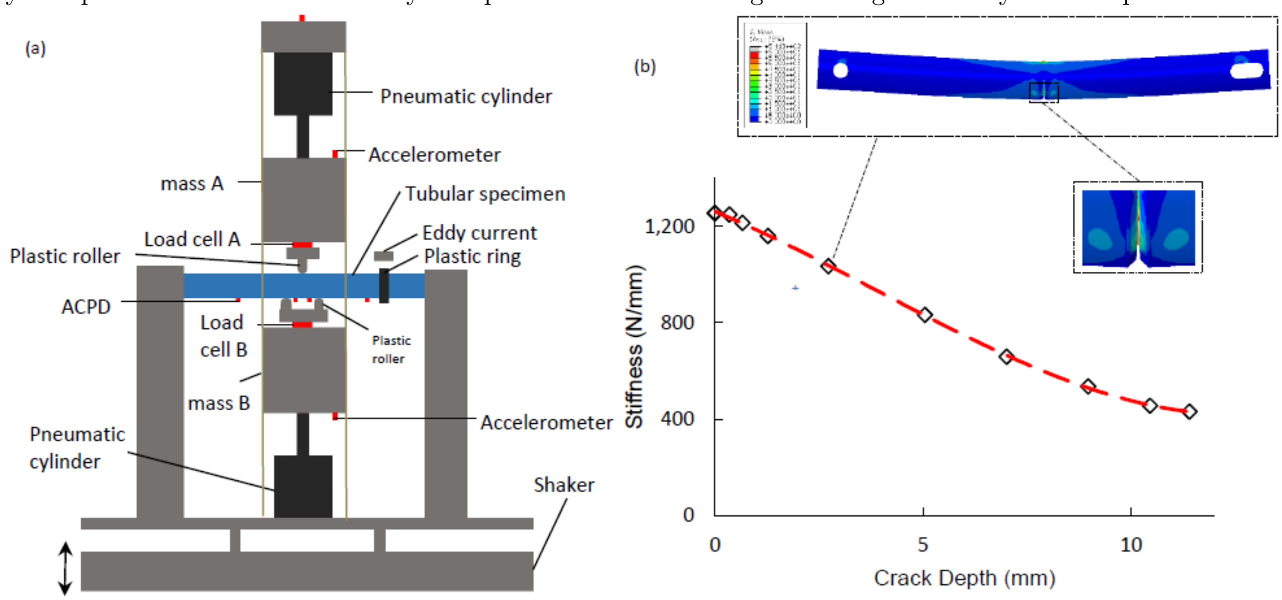

Figure 1: (a) Schematic diagram of the modified experimental fatigue rig. The electromechanical shaker provides a base excitation to the experimental rig so that cyclic stresses in the tubular specimen and initiate and propagate cracks. Two force sensors and three accelerometers combined with the proximity sensor (eddy current) and alternating current potential difference (ACPD) measurement setup are shown. (b) Cracked tubular specimen stiffness curve from 10 finite element models.

Keywords: Fatigue, Crack Growth, Mathematical Model

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NONLINEAR DYNAMICS OF LUMP MASS MODEL OF DRILL-STRING IN HORIZONTAL WELL

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ABSTRACT

We develop a dynamic model of a drill-string in a horizontal well having six degrees-of-freedom, which accounts for longitudinal, lateral and torsional motions. In this model, nonlinearities that arise due to intermittent contacts of a drill-pipe with a borehole wall and complex interactions between a drill-bit and a rock formation are all considered. The lateral motions of the drill-bit are restricted and its interactions with a borehole generate an interlaced force being result of a friction and a cutting that has a regenerative effect. In the cutting process, a state-dependent time delay is introduced to couple the axial and torsional motions of the drill-bit. The dynamic model established in this article is tested where the friction and cutting effects are gradually switched on, which shows that the model is robust. Subsequently, the complex whirling of a horizontal drill-string is analyzed and a particular attention is given to the influence of driving rotation speed and dynamic friction coefficient. The study should help us to better understand nonlinear dynamic effects of drill-strings in horizontal wells, which will lay a foundation for optimizing drilling parameters.

Keywords: Horizontal well, Drill-string dynamics, Coupled motions, State-dependent delay, Complex whirling

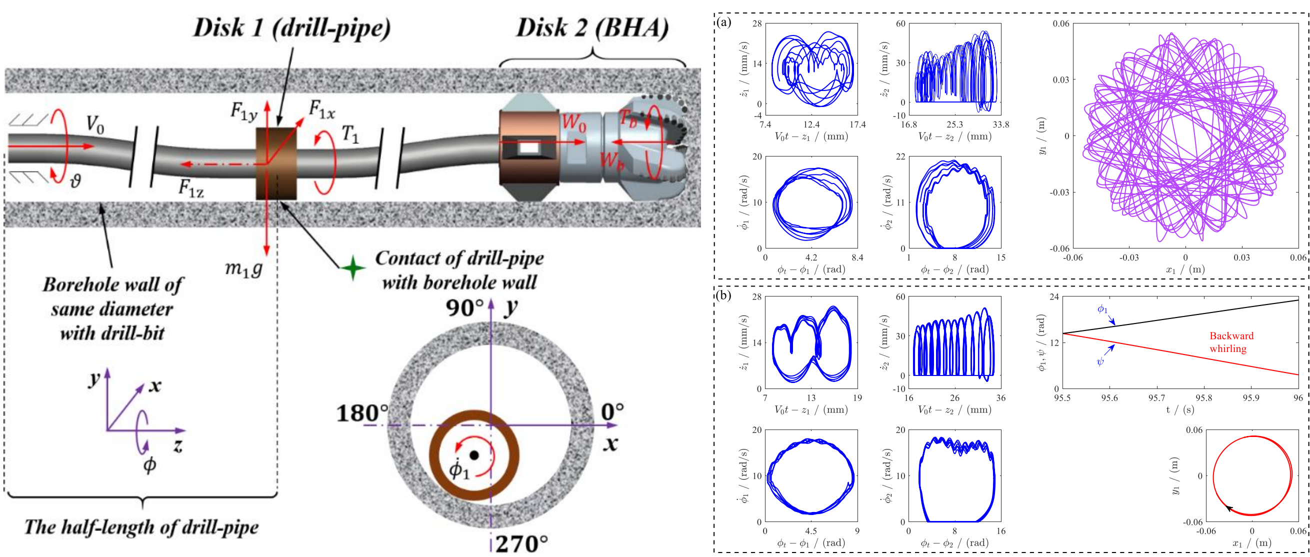

Figure 1: Graphical Abstract

ACTIVE CONTROL OF NONSTATIONARY VIBRATIONS IN PLATES UNDER DYNAMIC LOADING

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ABSTRACT

The current study is devoted to the development of active control methods for the nonstationary vibrations of the rectangular isotropic elastic plate of medium thickness under dynamic transverse concentrated loading P(t) (Fig. 1).

The direct problem (finding the dynamic distribution of the plate deflection) is solved analytically. The system of partial differential equations is solved using the Fourier series and the Laplace integral transform. The solution is written in the form of the Duhamel integral (of the convolution type) with finite-difference Cauchy kernels.

To solve the vibration control problem (to minimize or, if possible, fully eliminate the deflection) the additional control loads $P^c(t)$ are applied to the mechanical system. The necessary control loads are determined from the solution of system of Volterra integral equations, which has been obtained on the base of the direct problem solution. Furthermore, Tikhonov regularization algorithm is used to numerically solve the ill-posed system of equations (system of Volterra integral equations). An appropriate choice of the control loading points the distribution of the loading in time can significantly reduce the amplitudes of normal displacements of the plate [1, 2].

An approximate solution of the problem is obtained using the numerical-analytical method. The resulting deflections of the median plane are presented for different combinations of the disturbing load and control functions. The advantages and disadvantages of particular control systems and possibility of their practical implementation are discussed.

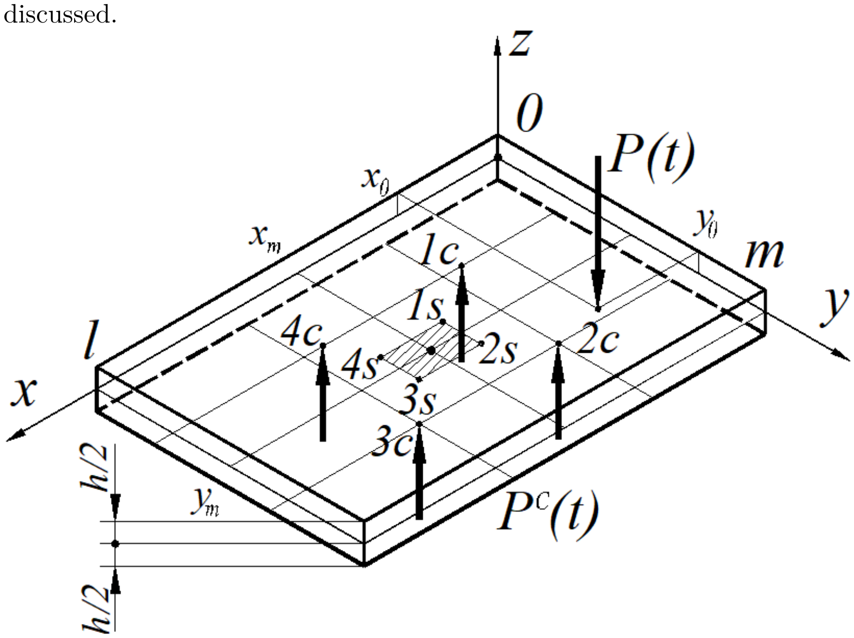

Figure 1: Plate under dynamic loading

Keywords: Volterra Integral Equation, Timoshenko Plate, Nonstationary Loading, Vibration Control, Inverse Problem, Ill-posed Problem; Tikhonov Regularization.

[1] Yanyutin, E. G. and Voropay, A. V. 2004 Controlling nonstationary vibrations of a plate by means of additional loads. *International Journal of Solids and Structures* **41**, 4919–4926.

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