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A NUMERICAL STUDY ON SHIFT MANIPULATION OF INTRINSIC LOCALIZED MODE IN AC DRIVEN KLEIN GORDON LATTICE

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ABSTRACT

Various vibration phenomena occur in the nonlinear lattice which describes the dynamics of various periodic structures. In the nonlinear lattice, despite the absence of defects or disorder, the spatially localized and temporally periodic solution appears due to its nonlinearity and discreteness[1]. The localized vibrational mode is called Intrinsic Localized Mode (ILM) or Discrete Breather (DB). Recently, It has become considered that ILM is available to energy management in a device, energy harvesting, and phonon engineering.

Manipulation of ILM has become an important issue for these engineering applications. Up to now, generation, annihilation and shift manipulation of ILM is numerically and experimentally discussed in coupled cantilever arrays[2] and nonlinear transmission lines[3]. However, this manipulation is achieved heuristically in previous work. Thus, the processes of manipulating ILM is still poorly understood.

In this study, we discuss shift manipulation of ILM in the ac driven Klein Gordon lattice. Figure 1 shows the ac driven Klein Gordon lattice. Klein Gordon lattice is a system of nonlinear oscillators jointed by harmonic spring. Each oscillator is periodically driven in the reverse phase. We analyzed the 2-degree nonlinear system which is a reduction system of the ac driven Klein Gordon lattice. Based on the analysis, we consider that shift manipulation of ILM is achieved by changing the coupling constant between targeted sites adiabatically. Figure 2 (a) presents the time development of the coupling constant. Figure 2 (b) shows the time development of ILM when the coupling constant vary as shown in Figure 2 (a). Shift manipulation of ILM has succeeded in this case. Further numerical experiments indicate that shift manipulation of ILM depends on T_{C} which is a period keeping the coupling constant. Besides, we cannot shift ILM definitely since fractal structure about the result of this manipulation appears in some region of T_{C}.

In this study, we have shown a method of shift manipulation of ILM in the ac Klein Gordon lattice. This study seems to contribute ILM manipulation in the nonlinear lattice and its engineering applications.

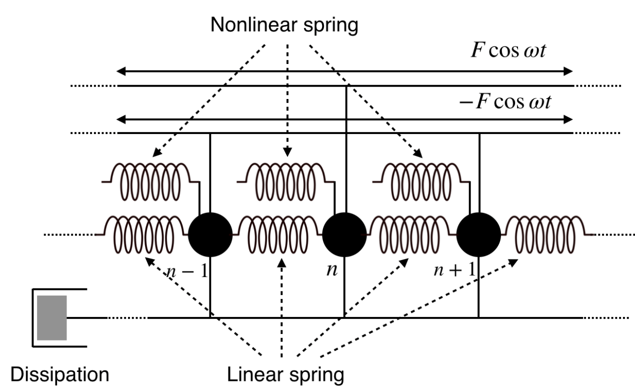

Figure 1: AC driven Klein Gordon lattice.

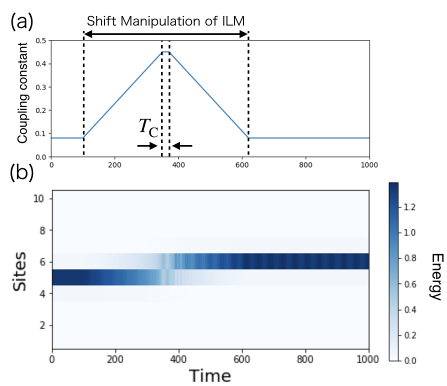

Figure 2: Time development of the coupling constant and energy of each sites.

Keywords: Klein Gordon Lattice, Intrinsic Localized Mode, Adiabatic Process, Fractal

[1] Sievers, A. J. and Takeno, S. 1988 Intrinsic localized mode in anharmonic crystals. *Physical Review Letters* **61**, 970 - 973.

[2] Sato, M. Hubbard, B. E. and Sievers, A. J. 2006 Colloquium: Nonlinear Energy Localization and Its Manipulation in Micromechanical Oscillator Arrays. *Reviews of Modern Physics* **78**, 137 - 157.

[3] Sato, M. Yasui, S. Kimura, M. Hikihara, T. and Sievers, A. J. 2007 Management of Localized Energy in Discrete Nonlinear Transmission Lines. *Europhysics Letters* **8**, 30002.

DESIGN AND TESTING OF RESONANCE ENHANCED SCALE MILLING TOOL FOR HARD SCALES

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ABSTRACT

Mature fields have shown a drastic oil and gas production decline due to oilfield scales which result in revenues reduction. Scale builds up inside the wellbore tubular, clogging the well, eventually hindering the production and minimizing the flow area. Different methods are used for scale removal, but hard scale is a challenging issue which companies are facing [1-2]. Therefore, it is vital to improve existing and develop new methods of scale removal, that are more efficient, fast, and non-destructive to the wellbore. Resonance Enhanced Drilling (RED) technology, developed originally for well construction at the Centre for Applied Dynamics Research (CADR), University of Aberdeen, is currently being tested and adjusted for scale removal. This technology generates dynamic stress using high frequency axial vibration accompanied by rotary action, thus producing a resonance condition between the drill-bit and the formation [2-3]. The RED technology is expected to enhance a fast milling of scale, providing environmental and cost benefits for downhole milling. The objective of this study is to design, develop, optimize and test a new Resonance Enhanced Scale Milling (RESM) tool, leading to a full-scale field trial. A series of careful experiments using standard milling drill-bits and scale representative concrete samples, provided by industrial collaborator, have been conducted by setting the parameters of rotational velocity at 25 rpm, WOB at 1.2 kN, and RED frequency between 110 to 240 Hz. From the initial results, RED seems to have significant influence on milling rate in the laboratory conditions, where ROP using the conventional milling was 0.23 mm/s whereas using RED was up to 2.26 mm/s, showing improvements up to 995% in ROP. Similar enhancements in ROP have been observed in wide ranges of operating parameters (WOB and angular velocity). A comparison of the RED performance with 3.625” milling bit at different RED frequencies is shown in Figure 1, for rotational velocities 25 and 60 rpm, respectively. Based on the experiments and analysis undertaken, it can be concluded that RED technology has a great impact on increasing the milling rate. Modification on the design is being set in order to conduct a field trial.

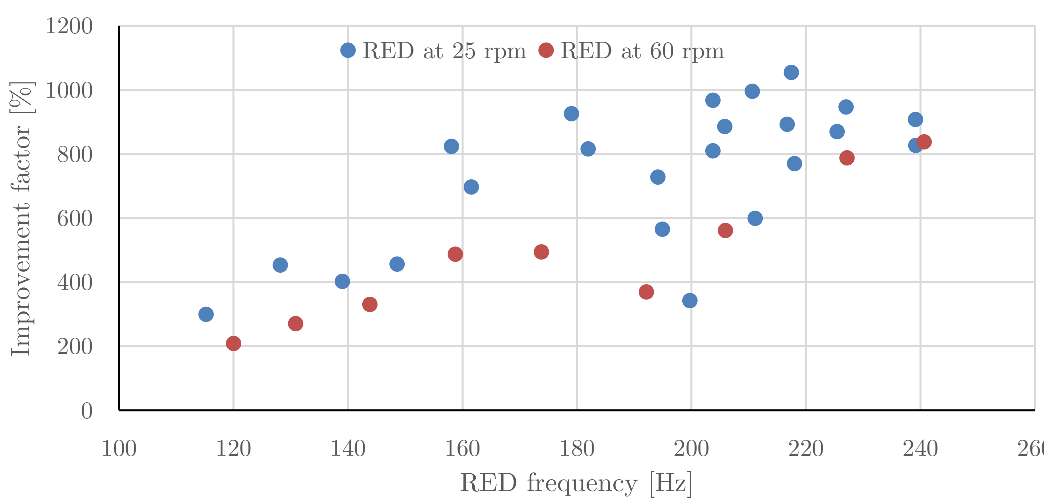

Figure 1: RED performance with 3.625” milling bit at both rotational velocities 25 and 60 rpm

Keywords: Milling, Scale, Drilling, Experimental studies.

Acknowledgement: The authors would like to acknowledge the support of Oil & Gas Innovation Centre (OGIC), and Welltec AS.

[1] Frenier, W.W., Ziauddin, M. 2008. Formation, removal, and inhibition of inorganic scale in the oilfield environment. *Society of Petroleum Engineers*. 230.
[2] Brown, M. 1998. Full Scale Attack. The BP Technology Magazine: 30-32.
[3] Wiercigroch, M. 2007. Resonance Enhanced Drilling: Method and Apparatus, patent No. WO2007141550.
[4] Pavlovskaia, E., Hendry, D., Wiercigroch, M. 2014. Modelling of high frequency vibro-impact drilling. *International Journal of Mechanical Sciences*. 91, 110-119.

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On the crack-tip stress field due to the presence of isotropic dilatational inclusion: Theoretical and numerical analysis

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ABSTRACT

In this study, the stress field at the crack-tip of a semi-infinite crack interacting with an isotropic dilatational inclusion is studied. The fundamental solution of an eigenstrain point interacting with a semi-infinite crack is presented first [1]. With the solution serving as Green's function, the Kolosov-Muskhelishvili complex potentials for a crack enclosed by a homogenous inclusion are formulated. Then the exact analytical stress distribution along the crack propagation line is derived and the full-field asymptotic stress distribution in the vicinity of the crack-tip are acquired through Taylor series method. Finally, numerical method is also performed, which not only reveals the distribution of the stress field, but also validates the theoretical analysis. As expected, theoretical and numerical results show that the presence of dilatational inclusion will produce a significant shielding (or anti-shielding) effect on crack-tip. Interestingly, it is found that a stress jump occurs at the interface of inclusion and matrix, which may unexpectedly trigger a micro-damage prior to the crack advance. This mechanism is capable of leading to crack propagation fundamentally, when it is exposed to an oxidizing or corrosive environment.

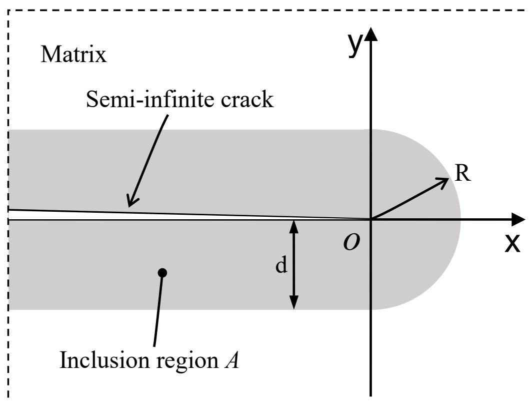

Figure 1: An opening semi-infinite crack enclosed by inclusion. "R" refers to the radius of the inclusion on tip, "d" is the depth of inclusion with respect to crack surface, and in this model *R=d.*

Keywords: Crack-tip, homogeneous inclusion, stress field, stress jump, Greens' function

[1]Ma L.F. 2010 Fundamental formulation for transformation toughening. International Journal of Solids and Structures 47, 3214-3220.

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TRACKING SURVIVABILITY OF SOLUTIONS IN NON-LINEAR DYNAMICAL SYSTEMS

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ABSTRACT

This work aims at quantifying the likelihood as well as the resilience of mono or multi-stable stochastic systems during their transience to leaving their corresponding region of desirable states. This likelihood, also knows as survivability $(S(t))$, denotes the fraction of initial conditions giving rise to trajectories that stay within a desirable region $(X_A{}^+ \subset X_A)$, where X_A denotes the basin of attraction of an attractor A for time t [1]. As an example, if during the transient period the system of a certain power-grid, it reaches a peak of current that drives the system to a state of failure, this system would not be operational beyond this event. However, in methods like basin stability, as a stable attractor is subsequently reached, the latter analysis would show the system to be in a stable state for the prescribed initial condition that leads it to failure during the transient period [2]. The notion of survivability could thereby serve as a better estimate to demarcate a system's stable operational ranges.

The simplest example could be of a Duffing oscillator with two potential wells where transient inter-well vibrations can eventually transition into intra-well oscillators as time elapses. The phenomenon of transient chaos in such a system has been well documented [3]. In physical terms, this system models an elastic pendulum whose spring's stiffness does not exactly obey Hooke's law or a snap-through truss system [3]. Attaining the second co-existing state might not be a desirable phenomenon for the physical system this model governs and thus it is of paramount importance to study the transience characteristics of the system. The problem is more involved when it is continually dislogded by noise. The equation

$$\mathrm{d}x = x'\,\mathrm{d}t \tag{1a}$$

$$\mathrm{d}x' = (-\delta x' - \beta x - \alpha x^3)\,\mathrm{d}t + A\cos(\omega t)\,\mathrm{d}t + \sigma\,\mathrm{d}W \tag{1b}$$

with $\delta = 0.05, \beta = 1, \alpha = 1, A = 0.1, \omega = 1.1$ is solved for $t = 30$. The deterministic transience for the system 1 is shown in Fig. 1 (a). The system eventually ends up at a period 1 attractor as it loses energy ($E = \frac{1}{2}mx'^2 + \beta\frac{x^2}{2} + \alpha\frac{x^4}{4}$). In the presence of noise, the system is contained in one of the potential wells for a marginal level of noise and as it does so, has a directed oscillation which is wider spread across $x'(t)$ as can be seen in Fig. 1(b). Eventually with the increase of noise, there are intra-well hops; See Fig. 1(c), even though beyond transience the system is contained in one of the wells for a time $t > 10\frac{2\pi}{\omega}$.

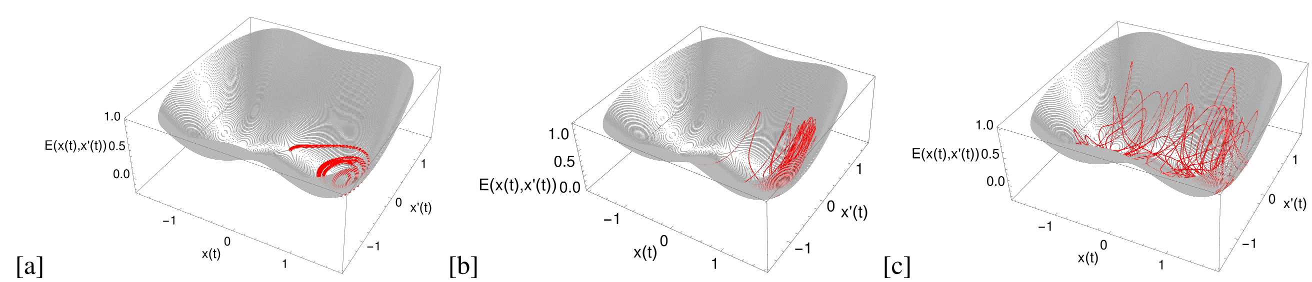

Figure 1: The behaviour of a stochastic damped forced Duffing oscillator with- (a) $\sigma = 0$ (b) $\sigma = 0.015$ (c) $\sigma = 0.1$

The aim is to demarcate the finite time or $t - time$ basin of survival $S(t)$ of such solutions in the desirable regions $X^+ \subset X$ with a certain confidence level in the presence of noise.

Keywords: Transient resilience, Survivability, Stochastic calculus

[1] Hellmann, F., Schultz, P., Grabow, C., Heitzig, J., & Kurths, J. 2015. *Survivability: A unifiying concept for the transient resilience of deterministic dynamical systems.* **arXiv**.

[2] Menck, P. J., Heitzig, J., Marwan, N., Kurths, J. 2013. *How basin stability complements the linear-stability paradigm.* Nature physics, **9(2), 89-92**.

[3] Venkatesan, A., Lakshmanan, M. 1997. *Bifurcation and chaos in the double-well Duffing–Van der Pol oscillator: Numerical and analytical studies.* Physical Review E, **56(6), 6321**.

CONTROL OF CYCLIC SYSTEMS

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ABSTRACT

The model reduction method – called Routh reduction [1] – for cyclic systems is well-known in mechanics. A cyclic mechanical system can be easily identified: the Lagrangian function is independent of some generalized coordinates, which are the so-called the cyclic coordinates. The main idea is the separation of essential and cyclic coordinates and the introduction of generalized momenta for cyclic coordinate velocities. The Hamiltonian description is used for the cyclic coordinates, while the Lagrangian form is kept for the essential motion. In the original form of Routh reduction, only conservative mechanical systems were assumed, so the general forces applied for control purposes were excluded. Using the conservation of generalized momenta, the model reduction can always be carried out and the cyclic dynamics is decoupled from the essential motion.

The Routh reduction is extended in order to exploit its benefits in case of controlled systems. The generalized forces are assumed along the cyclic coordinates only, the essential coordinates are free from external effects and they can be influenced through the dynamical coupling only. This may seem like a strong assumption, but this is the usual case in real underactuated systems, like inverted pendulums, simple rotor models and underactuated robots. The applied generalized control forces are assumed to be the function of the essential positions and velocities only, so the control force is independent of the cyclic coordinates. This is a necessary requirement, since the aim is to reduce the model by eliminating the cyclic coordinates and velocities.

The reduced nonlinear model can be obtained only if the essential motion is independent of the cyclic generalized momenta. Generally, a reduced nonlinear model cannot be obtained, because the generalized momenta are varied by the external forces, so conservation of generalized momenta does not hold, opposite to the case of conservative systems. Reduced linear models can be derived if an extra condition is fulfilled, which guarantees that the linear model depends only on the generalized momenta corresponding to the specific stationary motion the system is linearized around; so the linear model is independent of the instantaneous generalized momenta. The static equilibrium is covered as well, since it is a special stationary motion with zero generalized momenta. Based on these reduced linear models, the state-space model can be derived in closed form, and a necessary condition of controllability is stated. The controllability of such systems can be excluded by knowing only the kinetic energy of the mechanical system. If further investigations are necessary, the Kalman's controllability criterion [2] may be used.

This formalism makes it possible to investigate the control around the equilibrium and steady-state motion together by using the same state-space model of cyclic mechanical systems. Moreover, the model size – the number of first order linear differential equations required to describe the dynamical behavior – is decreased by the number of cyclic positions and velocities.

ACKNOWLEDGMENT

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Keywords: Cyclic systems, Controllability, Model reduction

[1] Routh, E. J., 1860. *The elementary part of a treatise on the dynamics of a system of rigid bodies*. Macmillan and Company.

[2] Kalman, R. E., 1963. Mathematical description of linear dynamical systems. *Journal of the Society for Industrial and Applied Mathematics*, Series A: Control, 1(2), pp.152-192.

DEVELOPMENT OF A VIBRO-IMPACT SELF-PROPELLED CAPSULE IN MILLIMETRE-SCALE

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ABSTRACT

In this work, the development of a standard-sized vibro-impact capsule prototype (26 mm in length and 11 mm in diameter) for gastrointestinal endoscopy is presented with extensive experimental results regarding to its progression speeds under different frictional environments. The driving principle of the prototype was inspirited by the non-smooth dynamical system studied in [1] by employing a small magnetic actuation section inside the capsule excited by an external magnetic field. Conceptual model of the capsule is presented in Figure 1 (a), and its prototype is shown in Figure 1 (b), where the rectilinear motion of the capsule is generated using a periodically driven permanent magnet interacting with the capsule's main body as a hammer via the primary and the secondary constraints.

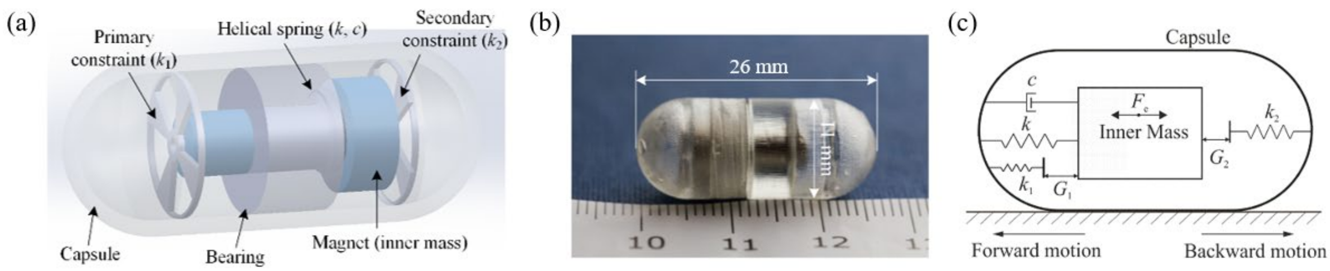

Figure 1. (a) Conceptual design, (b) 3D-printed prototype, and (c) physical model of the vibro-impact self-propelled capsule

A mathematical model showing an inner vibrational mass M_m, a total capsule mass M_c, a helical spring with the stiffness *k and the* damping ratio *c,* two constraints' stiffness k_1 and k_2, is considered in Figure 1 (c). Other identified parameters include the friction coefficient between the capsule and the synthetic intestine μ, the gaps between the inner mass and two constraints G_1 and G_2, the magnetic driving force F_e, and the duty cycle of the external excitation *D*. All the parameters were measured and used in both numerical simulation and experiment.
Schematics of the experimental setup and its photograph are shown in Figure 2 (a) and (b), respectively, where the coils were controlled by a drive circuit triggered by a pulse-width modulation (PWM) signal. A video camera was used to record the locomotion of the capsule, and the recorded video clip was analyzed by using Tracker [2], a real-time tracking software for visualizing the time histories of capsule's displacement as illustrated in Figure 2 (c) and (d).

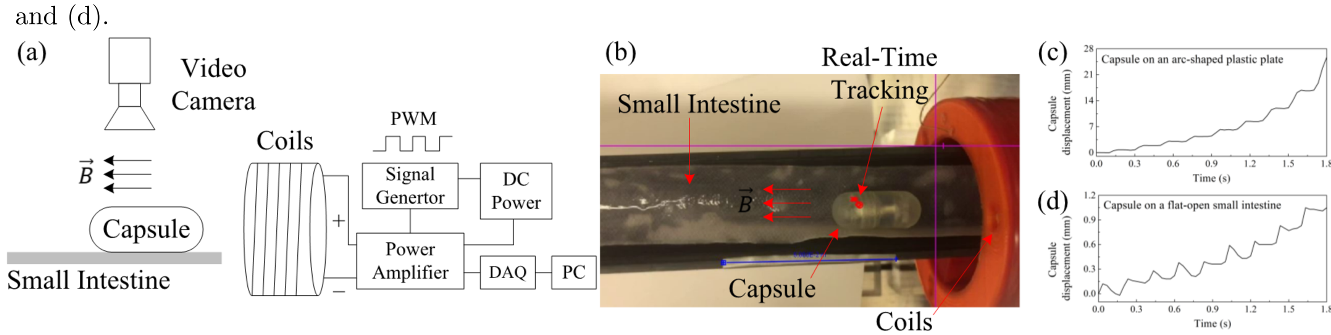

Figure 2. (a) Schematics and (b) photograph of the experimental setup. Time histories of capsule's displacement (c) on an arc-shaped plastic plate and (d) on a flat-open small intestine.

Keywords: Capsule endoscopy, Vibro-impact, Self-propulsion, Non-smooth system.

[1] Liu Y, Pavlovskaia E, and Wiercigroch M. 2015 Experimental verification of the vibro-impact capsule model, *Nonlinear Dynamics*, 83, 1029–1041.

[2] Tracker, web site https://physlets.org/tracker/.

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A COMPARATIVE STUDY ON VIBRO-DRIVEN CAPSUBOT

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ABSTRACT

This report presents a comparative study on five different models of vibration-driven capsubot system. To date, the system can be excited either by sinousoidal (1), periodic (2) or squared (3). In this study, we summary five different modes of excitation and impact conditions, including sinousoidal, squared and half-sine excitation, with and without impacts. An experimental setup, as shown in Figure 1, is implemented to verify the simulation analysys.

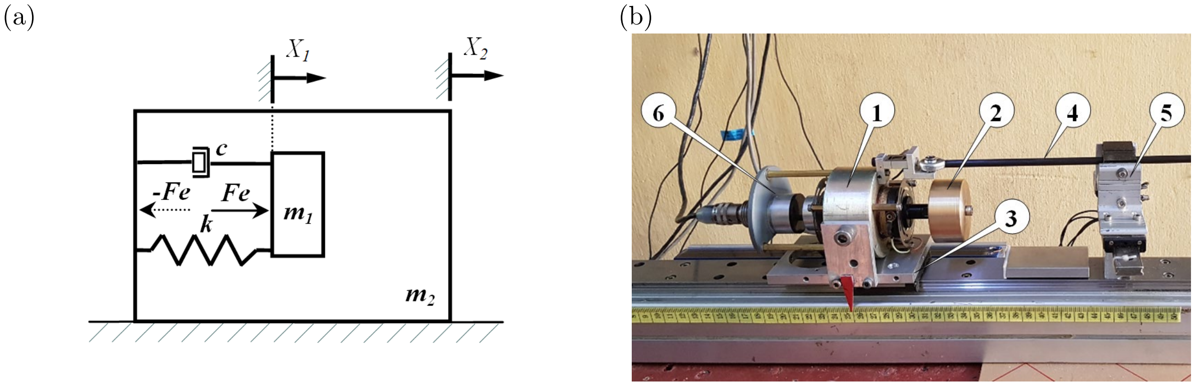

Figure 1: Experimental setup of capsubot: a) the model and b) real apparatus

Keywords: Capsubot, vibration-driven, vibro-impact, periodic excitation

[1] Guo, B., Liu. Y., Birler, R. and Prasad S. 2020 Self-propelled capsule endoscopy for small-bowel examination: Proof-of-concept and model verification. *International Journal of Mechanical Sciences* 174,105506.

[2] Nunuparov, A., Becker F., Bolotnik and N., Zeidis, I. and Zimmermann K. 2019 Dynamics and motion control of a capsule robot with an opposing spring. *Archive of Applied Mechanics* 89(10), 2193-208.

[3] Duong, T-H., Nguyen, V-D. and La, N-T. 2018 A new autogenous mobile system driven by vibration without impacts, excited by an impulse periodic force. *MATEC Web Conf.* 148:04005.

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DYNAMICS ANALYSIS OF CANTILEVER ACTIVE BIMORPH BEAM WITH ELECTRO-MAGNETO-MECHANICAL COUPLING MODEL

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ABSTRACT

A slender, cantilever and elastic composite beam is taken under consideration. Two piezoelectric layers are embedded on top and bottom surfaces of the beam as shown in figure 1, which ensure symmetry of the structure relative to axis OX. Beam cross-section is assumed to be constant spanwise and its length, height and width is denoted by l, h and b respectively. A mathematical model of the structure assumes that the shape of the cross-section is maintained in its plane and warping out of plane is not allowed. Timoshenko beam theory is taken into account because of the composite used in the structure [2]. The beam core composite material is linearly elastic and orthotropic; classic laminate theory is implemented. Non-linear constitutive equations for piezoelectric material are developed according to Joshi's paper [1].

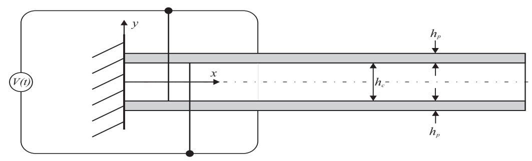

Figure 1: Composite beam with two actuators

The set of partial differential equations of motion with full electro-magneto-mechanical coupling is derived from the extended Hamilton's principle of least action

$$\delta J = \int_{t1}^{t2} (\delta T - \delta(U_m + U_e) + \delta B + \delta W_{ext})dt = 0 \tag{1}$$

where J is the action, T is kinetic energy, U_m and U_e are mechanical and electrical components of potential energy respectively, B is magnetic energy, and W_{ext} is the term for work done by external loads.

Piezoelectric materials exhibit direct and converse effects which are the source of the electromechanical coupling in the model. Therefore polarized ceramics like PZT-G1195 [3] are often used in beam-like structures for energy harvesting, vibration control, as sensors etc. Since PZTs exhibit transverse isotropic properties the constitutive relations have to be formulated accordingly. The full non-linear coupled equations (2) are derived based on fundamental work by Joshi [1]. These may be considered as a combination between Maxwell's law of electromagnetism and equations of motion of a deformable body.

$$\begin{aligned} \sigma_{pij} &= C_{ijlm}\varepsilon_{lm} - h_{ijn}D_n + \frac{1}{2}h_{ijnr}D_nD_r \\ E_k &= -h_{klm}\varepsilon_{lm} + \beta_{kn}D_n + \frac{1}{2}\beta_{knr}D_nD_r \end{aligned} \tag{2}$$

where C_{ijlm} stands for the second order piezoceramic elasticity tensor at constant electric displacement vector, h_{ijn} is piezoelectric constant tensor and $h_{ijn} = h^T_{klm}$, β_{kn} are components of the impermittivity tensor, h_{ijnr} and β_{knr} is electroelastic strain and dielectric coefficients vectors related to non-linear electric displacement tensors D_nD_r. The extended Hamilton's least action principle (1) yields the system of three fully coupled equations of motion of flexible composite beam with piezoelectric patches. These equations are used to determine dynamic characteristics of the structure and vibrations control.

Keywords: Non-linear piezoelectric effect, coupled-field problem, composite Timoshenko beam

Acknowledgment The work is financially supported by grant 12-2016/23/B/ST8/01865 from the Polish National Science Centre.

[1] JOSHI, S. P. Non-linear constitutive relations for piezoceramic materials. *Smart Materials and Structures 1*, 1 (1992), 80–83.

[2] LATALSKI, J. A coupled-field model of a rotating composite beam with an integrated nonlinear piezoelectric active element. *Nonlinear Dynamics 90*, 3 (2017), 2145–2162.

[3] RAO, M. N., SCHMIDT, R., AND SCHRÖDER, K. U. Static and dynamic fe analysis of piezolaminated composite shells considering electric field nonlinearity under thermo-electro-mechanical loads. *Acta Mechanica 229*, 12 (2018), 5093–5120.