Post-critical vibrations in an auto-resonant axial-torsional vibratory drilling system

Alexander Gouskov[*], Mikhail Guskov[**]
[*]*Department of Applied Mechanics, Bauman Moscow State Technical University, Moscow, Russia,*
[**]*PIMM Laboratory – ENSAM, CNAM, CNRS, Paris, France*

Summary. Auto-excitation in a torsional-axial vibratory drilling device is investigated on a 2DOF model in time domain. A non-linear tool-workpiece interaction approach, based on fractional-rational cutting law and state-dependent delay is used. Scanning the design parameters space in the vicinity of chatter instability boundaries reveals a hysteresis effect with a jump phenomenon in magnitude, characteristic of subcritical bifurcation. It is shown that the helix angle parameter, driving the cross-coupling in torsional and axial compliances of the device, has strong influence on the stability lobes. This would open a possibility to adjust the device's properties to given reguirements.

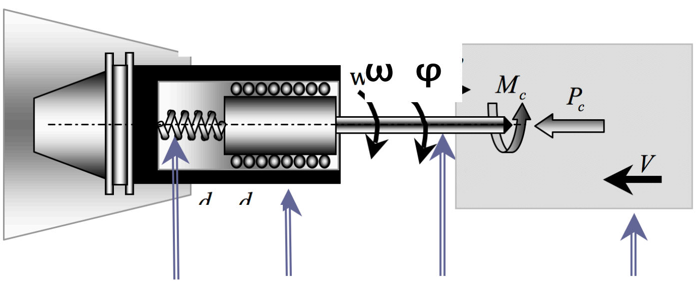
Introduction

Use of axial vibrations in drilling to enhance productivity and equipment durability is a spreading approach. Several solutions based on axial self-excitation [1] or forcing [2, 3] are now known. This work is focused on a novel, axial-torsional self-excited system. Linear stability if such system has been investigated [4], and the purpose of the present work is to analyze its vibration regimes under chatter.

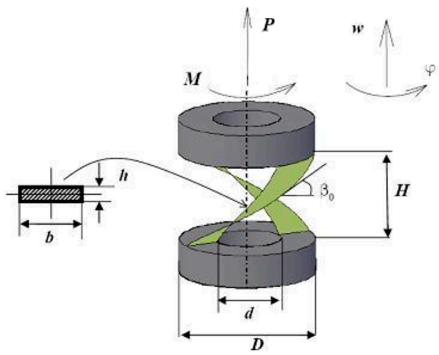
Modelling approach: 2DOF system with non-linear cutting force model

Vibratory drilling head: principle and 2DOF model

The principle schematic of this system is shown on Fig. 1. In such system, an elastic spring element is used, that features coupled axial and torsional compliance, due to the helical shape (schematic design presented on Fig. 1b).



a) drilling process schematic



b) spring element

Figure 1. Vibrational drilling head

The kinematics of the tool is described by 2 degrees of freedom, namely axial translation *w* and torsional angle. A 2DOF model is adopted for this system, based on the tool axial and torsional vibrations.

Tool-workpiece interaction

The cutting forces and moments are taken into account by means of a fractional cutting law [5]: the force is determined as a non-linear function of the cut thickness and the moment is expressed as a multiple of the force. The cut thickness is a function of axial feed and the delay term defining the surface left by the previous edge passage. The delay in itself is variable due to the torsional compliance of the tool holder system.
The surface generation is modeled by a non-linear function observing the presence of cut, in order to take the cut interruptions into account.

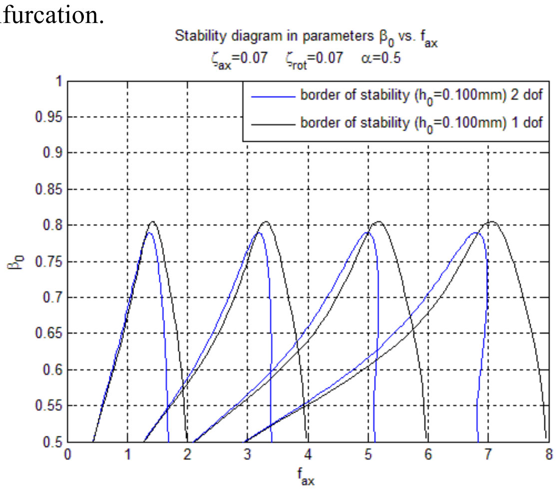
Results and discussion: chatter zones and hysteresis effect

Excitability investigation

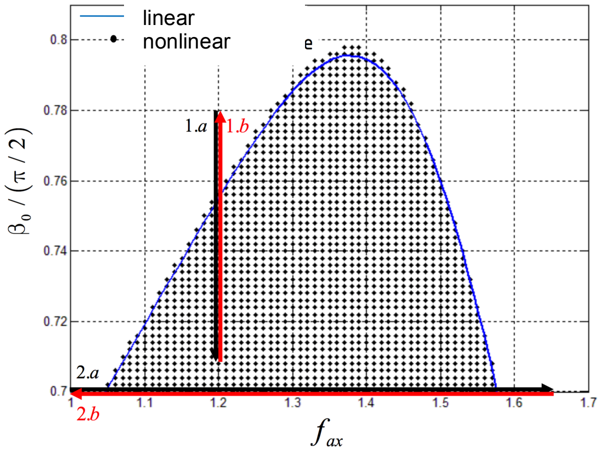
Stability analysis [4] of the stationery cut reveals the presence of instabililty regions in the parameter space β_0—f_{ax} (helix angle – axial vibration eigenfrequency), shown on Fig. 2a. These instabilities involve regenerative the chatter and enable the interrupted cut, which is sought for vibratory drilling. The shape of these instability regions is strongly dependent on the design and process parameters (cut thickness *h* corresponding to the feed rate), and the presence of torsional degree of freedom is also an important factor.

Time domain simulation for post-critical analysis

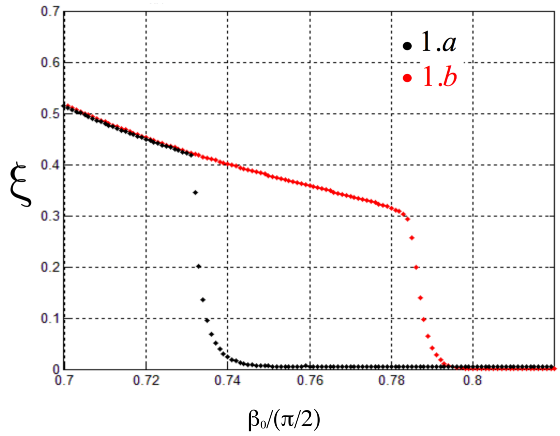
To evaluate the magnitudes of vibrations in the instable zones, time domain simulations are carried out. These simulations have shown the existence of multi-stable behavior in the vicinity of the stability region boundaries. A detailed analysis with the boundary trespassing in two directions shows hysteretic jump phenomenon, shown on Fig. 2c,d (Poincaré diagrams in ξ, dimensionless axial vibration magnitude), which is characteristic of subcritical bifurcation.



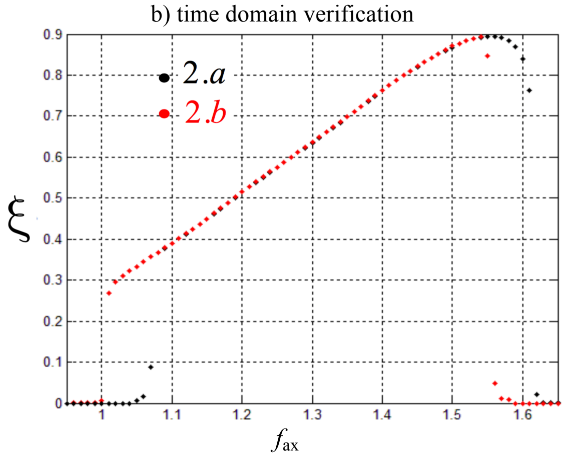
a) stability chart for stationery cut



b) time domain verification



c) Poincaré diagram for paths 1a,b from Fig. 2b



d) Poincaré diagram for paths 2a,b from Fig. 2b

Figure 2. Stability analysis

Acknowledgement

This work is supported by joint program of Russian Foundation for Basic Research (grant n° 16-58-150001) and of French National Scientific Research Center (grant PRC n° 263581)

References

[1] H. Paris, S. Tichkiewitch, and G. Peigne, (2005) "Modelling the vibratory drilling process to foresee cutting parameters," *CIRP Annals-Manufacturing Technology*, vol. 54, no. 1, pp. 367–370, 2005.

[2] A.-F. Boukari, J.-C. Carmona, G. Moraru, F. Malburet, A. Chaaba, and M. Douimi, (2011) "Piezo-actuators modeling for smart applications," *Mechatronics*, vol. 21, no. 1, pp. 339–349.

[3] M. Ladonne, Y. Landon, O. Cahuc, M. Cherif, J. Y. K'Nevez, and C. de Castelbajec (2013), "Modeling the chip morphology during Vibrations Assisted Drilling of Ti-6Al-4V", *Materials*

[4] D. Bondarenko, A. Gouskov, H. Paris, and B. Debray (2008), "Influence of tool torsion on the process stability of auto-vibratory drilling," in 2nd International Conference INTERCUT, Cluny, 2008.

[5] D. Brissaud, A. Gouskov, H. Paris, and S. Tichkiewitch (2008), "The fractional model for the determination of the cutting forces," Asian Int. J. of Science and Technology-Production and Manufacturing, vol. 1, pp. 17–25, 2008.