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Torsional vibration control of drill-string systems with time-varying measurement delays.

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Summary: This paper is concerned with torsional vibration control of drill-string systems. The objective is to develop a delay-dependent control scheme such that the downhole vibrations can be minimized by using ground measurement output with time-varying measurement delays. By regarding a drill-string as a series of lumped masses, a state space model is derived from a generic multi-degree-of-freedom model of the drill-string through a variable transformation. This provides the foundation of an observer-based output feedback control system, in which an internal model is inserted to represent the drill rig for improving the tracking performance, and a state observer is combined with a low-pass filter to estimate an equivalent effect of the downhole bit-rock interaction in the control input channel. To calculate the parameters of this control system, some sufficient conditions are derived in terms of linear-matrix-inequalities by taking into account a refined allowable delay set. It is shown through a numerical example that (i) the measurement of rotary table's angular displacement helps to produce less conservative results and (ii) a small measurement delay is beneficial for designing a controller with a smaller gain in the sense of Euclidean norm, however it may also result in a larger control torque by enhancing the bit-rock interaction.

MSC:

[93B52](#) Feedback control

[93C43](#) Delay control/observation systems

[70L05](#) Random vibrations in mechanics of particles and systems

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[drill-string systems](#); [state estimation](#); [output feedback control](#); [stick-slip vibrations](#); [time-varying delays](#)

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References:

- [1] Aarsnes, U. J.F.; Aamo, O. M., Linear stability analysis of self-excited vibrations in drilling using an infinite dimensional model, *J. Sound Vib.*, 360, 239-259 (2016)
- [2] Besselink, B.; Vromen, T.; Kremers, N.; van de Wouw, N., Analysis and control of stick-slip oscillations in drilling systems, *IEEE Trans. Control Syst. Technol.*, 24, 5, 1582-1593 (2016)
- [3] Canudas-de Wit, C.; Olsson, H.; Astrom, K.; Lischinsky, P., A new model for control of systems with friction, *IEEE Trans. Autom. Control*, 40, 3, 419-425 (1995) · [Zbl 0821.93007](#)
- [4] Canudas-de Wit, C.; Rubio, F.; Corchero, M., D-OSKIL: a new mechanism for controlling stick-slip oscillations in oil well drillstrings, *IEEE Trans. Control Syst. Technol.*, 16, 6, 1177-1191 (2008)
- [5] Chang, W. J.; Qiao, H. Y.; Ku, C. C., Sliding mode fuzzy control for nonlinear stochastic systems subject to pole assignment and variance constraint, *Inf. Sci.*, 432, 133-145 (2018)
- [6] Ghasemlooia, A.; Rideout, D. G.; Butt, S. D., A review of drillstring vibration modeling and suppression methods, *J. Pet. Sci. Eng.*, 131, 150-164 (2015)
- [7] Gupta, S. K.; Wahi, P., Tuned dynamics stabilizes an idealized regenerative axial-torsional model of rotary drilling, *J. Sound Vib.*, 412, 457-473 (2018)
- [8] Ho, D. W.; Lu, G., Robust stabilization for a class of discrete-time non-linear systems via output feedback: the unified LMI approach, *Int. J. Control*, 76, 2, 105-115 (2003) · [Zbl 1026.93048](#)
- [9] Kao, Y.; Xie, J.; Zhang, L.; Karimi, H. R., A sliding mode approach to robust stabilisation of markovian jump linear time-delay systems with generally incomplete transition rates, *Nonlin. Anal. Hybrid Syst.*, 17, 70-80 (2015) · [Zbl 1326.93111](#)
- [10] Karimi, H. R., A sliding mode approach to (h_∞) synchronization of master-slave time-delay systems with markovian jumping parameters and nonlinear uncertainties, *J. Franklin Inst.*, 349, 4, 1480-1496 (2012) · [Zbl 1254.93046](#)
- [11] Lian, Z.; He, Y.; Zhang, C. K.; Wu, M., Further robust stability analysis for uncertain takagi-sugeno fuzzy systems with time-varying delay via relaxed integral inequality, *Inf. Sci.*, 409, 139-150 (2017) · [Zbl 1432.93269](#)
- [12] Liu, Y., Suppressing stick-slip oscillations in underactuated multibody drill-strings with parametric uncertainties using sliding-

- mode control, *IET Control Theory Appl.*, 9, 1, 91-102 (2014)
- [13] Liu, X.; Yu, X.; Ma, G.; Xi, H., On sliding mode control for networked control systems with semi-markovian switching and random sensor delays, *Inf. Sci.*, 337, 44-58 (2016) · [Zbl 1396.93033](#)
- [14] Lin, W. J.; He, Y.; Zhang, C. K.; Long, F.; Wu, M., Dissipativity analysis for neural networks with two-delay components using an extended reciprocally convex matrix inequality, *Inf. Sci.*, 450, 169-181 (2018)
- [15] Lu, C.; Wu, M.; Chen, X.; Cao, W.; Gan, C.; She, J., Downhole-friction-estimation-based rotary speed control for drillstring system with stick-slip vibrations, *The Asian Control Conference, Gold Coast, Australia (2017)*, IEEE
- [16] Monteiro, H. L.; Trindade, M. A., Performance analysis of proportional-integral feedback control for the reduction of stick-slip-induced torsional vibrations in oil well drillstrings, *J. Sound Vib.*, 398, 28-38 (2017)
- [17] Nandakumar, K.; Wiercigroch, M., Stability analysis of a state dependent delayed, coupled two DOF model of drill-string vibration, *J. Sound Vib.*, 332, 10, 2575-2592 (2013)
- [18] Pathirana, P. N.; Nam, P. T.; Trinh, H., Stability of positive coupled differential-difference equations with unbounded time-varying delays, *Automatica*, 92, 259-263 (2018) · [Zbl 1417.93269](#)
- [19] Pavkovic, D.; Deur, J.; Lisac, A., A torque estimator-based control strategy for oil-well drill-string torsional vibrations active damping including an auto-tuning algorithm, *Control Eng. Pract.*, 19, 8, 836-850 (2011)
- [20] Richard, T.; Gernay, C.; Detournay, E., A simplified model to explore the root cause of stick-slip vibrations in drilling systems with drag bits, *J. Sound Vib.*, 305, 3, 432-456 (2007)
- [21] Saldivar, M. B.; Boussaada, I.; Mounier, H.; Niculescu, S. I., *Analysis and Control of Oilwell Drilling Vibrations: A Time-Delay Systems Approach (2015)*, Springer
- [22] Seuret, A.; Gouaisbaut, F., Wirtinger-based integral inequality: application to time-delay systems, *Automatica*, 49, 9, 2860-2866 (2013) · [Zbl 1364.93740](#)
- [23] Seuret, A.; Gouaisbaut, F., Stability of linear systems with time-varying delays using bessel-legendre inequalities, *IEEE Trans. Autom. Control*, 63, 1, 225-232 (2018) · [Zbl 1390.34213](#)
- [24] She, J.; Fang, M.; Ohyama, Y.; Hashimoto, H.; Wu, M., Improving disturbance-rejection performance based on an equivalent-input-disturbance approach, *IEEE Trans. Ind. Electron.*, 55, 1, 380-389 (2008)
- [25] Trinh, H.; Huong, D. C., A new method for designing distributed reduced-order functional observers of interconnected time-delay systems, *J. Franklin Inst.*, 355, 3, 1411-1451 (2018) · [Zbl 1393.93017](#)
- [26] Yigit, A. S.; Christoforou, A. P., Coupled torsional and bending vibrations of actively controlled drillstrings, *J. Sound Vib.*, 234, 1, 67-83 (2000)
- [27] Vromen, T.; Dai, C. H.; van de Wouw, N.; Oomen, T.; Astrid, P.; Nijmeijer, H., Robust output-feedback control to eliminate stick-slip oscillations in drill-string systems, *IFAC PapersOnLine*, 48, 6, 266-271 (2015)
- [28] Vromen, T.; van de Wouw, N.; Doris, A.; Astrid, P.; Nijmeijer, H., Nonlinear output-feedback control of torsional vibrations in drilling systems, *Int. J. Robust Nonlin. Control*, 27, 17, 3659-3684 (2017) · [Zbl 1386.93139](#)
- [29] Wang, Y.; Shen, H.; Karimi, H. R.; Duan, D., Dissipativity-based fuzzy integral sliding mode control of continuous-time T-S fuzzy systems, *IEEE Trans. Fuzzy Syst.*, 26, 3, 1164-1176 (2018)
- [30] Wang, Y.; Xia, Y.; Shen, H.; Zhou, P., SMC design for robust stabilization of nonlinear Markovian jump singular systems, *IEEE Trans. Autom. Control*, 63, 1, 219-224 (2018) · [Zbl 1390.93695](#)
- [31] Xiao, B.; Yin, S.; Kaynak, O., Tracking control of robotic manipulators with uncertain kinematics and dynamics, *IEEE Trans. Ind. Electron.*, 63, 10, 6439-6449 (2016)
- [32] Xiao, B.; Yin, S.; Gao, H., Reconfigurable tolerant control of uncertain mechanical systems with actuator faults: a sliding mode observer-based approach, *IEEE Trans. Control Syst. Technol.*, 26, 4, 1249-1258 (2018)
- [33] Xiao, B.; Dong, Q.; Ye, D.; Liu, L.; Huo, X., A general tracking control framework for uncertain systems with exponential convergence performance, *IEEE/ASME Trans. Mechatron.*, 23, 1, 111-120 (2018)
- [34] Yu, P.; Wu, M.; She, J.; Liu, K. Z.; Nakanishi, Y., An improved equivalent-input-disturbance approach for repetitive control system with state delay and disturbance, *IEEE Trans. Ind. Electron.*, 65, 1, 521-531 (2018)
- [35] Xiao, S. P.; Lian, H.; Zeng, H.; Chen, G.; Zheng, W., Analysis on robust passivity of uncertain neural networks with time-varying delays via free-matrix-based integral inequality, *Int. J. Control Autom. Syst.*, 15, 5, 2385-2394 (2017)
- [36] Zhang, B. L.; Han, Q. L.; Zhang, X. M.; Yu, X., Sliding mode control with mixed current and delayed states for offshore steel jacket platforms, *IEEE Trans. Control Syst. Technol.*, 22, 5, 1769-1783 (2014)
- [37] Zhang, B. L.; Han, Q. L.; Zhang, X. M., Event-triggered (h_{∞}) reliable control for offshore structures in network environments, *J. Sound Vib.*, 368, 1-21 (2016)
- [38] Zhang, B. L.; Han, Q. L.; Zhang, X. M., Recent advances in vibration control of offshore platforms, *Nonlinear Dyn.*, 89, 2, 755-771 (2017)
- [39] Zhang, C. K.; He, Y.; Jiang, L.; Wu, M., Stability analysis for delayed neural networks considering both conservativeness and complexity, *IEEE Trans. Neural Netw. Learn. Syst.*, 27, 7, 1486-1501 (2016)
- [40] Zhang, X. M.; Han, Q. L., Event-triggered (h_{∞}) control for a class of nonlinear networked control systems using novel integral inequalities, *Int. J. Robust Nonlinear Control*, 27, 4, 679-700 (2017) · [Zbl 1356.93058](#)
- [41] Zhang, X. M.; Han, Q. L., Network-based (h_{∞}) filtering using a logic jumping-like trigger, *Automatica*, 49, 5, 1428-1435 (2013) · [Zbl 1319.93076](#)
- [42] Zhang, X. M.; Han, Q. L., Abel lemma-based finite-sum inequality and its application to stability analysis for linear discrete

time-delay systems, *Automatica*, 57, 199-202 (2015) · [Zbl 1330.93213](#)

- [43] Zhang, X. M.; Han, Q. L.; Seuret, A.; Gouaisbaut, F., An improved reciprocally convex inequality and an augmented Lyapunov-Krasovskii functional for stability of linear systems with time-varying delay, *Automatica*, 84, 221-226 (2017) · [Zbl 1375.93114](#)
- [44] Zhang, X. M.; Han, Q. L.; Zeng, Z., Hierarchical type stability criteria for delayed neural networks via canonical besse-legendre inequalities, *IEEE Trans. Cybern.*, 48, 5, 1660-1671 (2018)
- [45] Zuo, Z.; Han, Q. L.; Ning, B.; Ge, X.; Zhang, X. M., An overview of recent advances in fixed-time cooperative control of multi-agent systems, *IEEE Trans. Ind. Inform.*, 14, 6, 2322-2334 (2018)

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