SOFT DRIVE

A Torsional Vibration Active Damping System Equipped with Back-Spinning Prevention

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Fig. 1. Soft Drive: from University laboratory to commercial field installation (Syria 2010).

Introduction

Many contemporary oil drilling rigs are still equipped with mature drilling equipment such as traditional speed-controlled top-drive units. Utilization of such "stiffly" controlled drilling drives, which do not account for drill-string compliance-related tool stick-slip effect [1], may, in turn, shorten the useful life of the drilling tool and other drill-string drive mechanical components. The drilling performance of these mature rigs can be improved by the addition of advanced drill-string rotational dynamics controls aimed at active torsional vibration suppression, which can enhance the efficiency and productivity of the drilling process. These active damping control strategies typically emulate a passive absorber behavior [2] by means of a robust single-loop drill-string PI speed controller tuned with respect to the drill-string drive resonant frequency [2, 3]. However, such a simple control strategy may not perform well under stuck tool conditions, resulting in hazardous back-spinning (back-lashing) drive behavior [3, 4] if proper drive stopping measures are not undertaken. Hence, the control strategy should be extended with a stuck tool condition detection system which unwinds the drill-string under speed control before it becomes dangerously strained, thus avoiding uncontrolled drilling drive behavior [3]. This short communication outlines the novel design of the rotary drilling drive active damping control system resulting from joint retrofitting R&D between industry and the university (Fig. 1).

Soft Drive System Overview

The Soft Drive active damping system, shown in Fig. 2, is based on a well-established proportional-integral (PI) speed controller for the rotary drilling electrical drive (top-drive), extended with operator's speed reference and torque limit modification scheme aimed at avoiding the potentially hazardous back-spinning motion under stuck tool conditions.

The PI speed controller tuning rules are aimed at achieving the nearest possible match with the so-called "optimal" controller tuning, wherein the closed-loop system behavior is characterized by small (typically 4-8%) step response overshoot. In order to achieve this, the PI controller proportional gain K_R and integral time constant T_I need to be related to the drill-string drive total inertia J_{tot}, and tool-side resonance frequency Ω_{02}, as presented in [3].

The active damping control strategy extension for the prevention of back-spinning effect [3] comprises a flip-flop logic (Fig. 2) which detects if the tool is stuck using a model-based drive speed prediction, while simultaneously a large torque demand m_{1R} is commanded to the motor. In that case, the flip-flop is set, and the speed reference is temporarily switched to a small negative value in order to unwind the drill-string in a controllable way. The speed reference ω_R is returned to the operator's reference $\omega_{R,op}$ (the flip-flop is reset) when the drill-string is sufficiently unwound.

Since stuck tool conditions correspond to constrained electrical drive motion, an additional torque reserve should be ensured in order to safely unwind the drill string during drive deceleration transient [3]. This torque reserve corresponds to the accumulated motor momentum under constrained motion conditions $J_1\omega_{1s}$ and the natural frequency of drilling motor vibrations Ω_{01} under stuck tool conditions (see [3]). The constrained motion motor speed ω_{1s} is readily available from the simplified dynamic model of drive speed behavior under stuck drill-string conditions (Fig. 2).

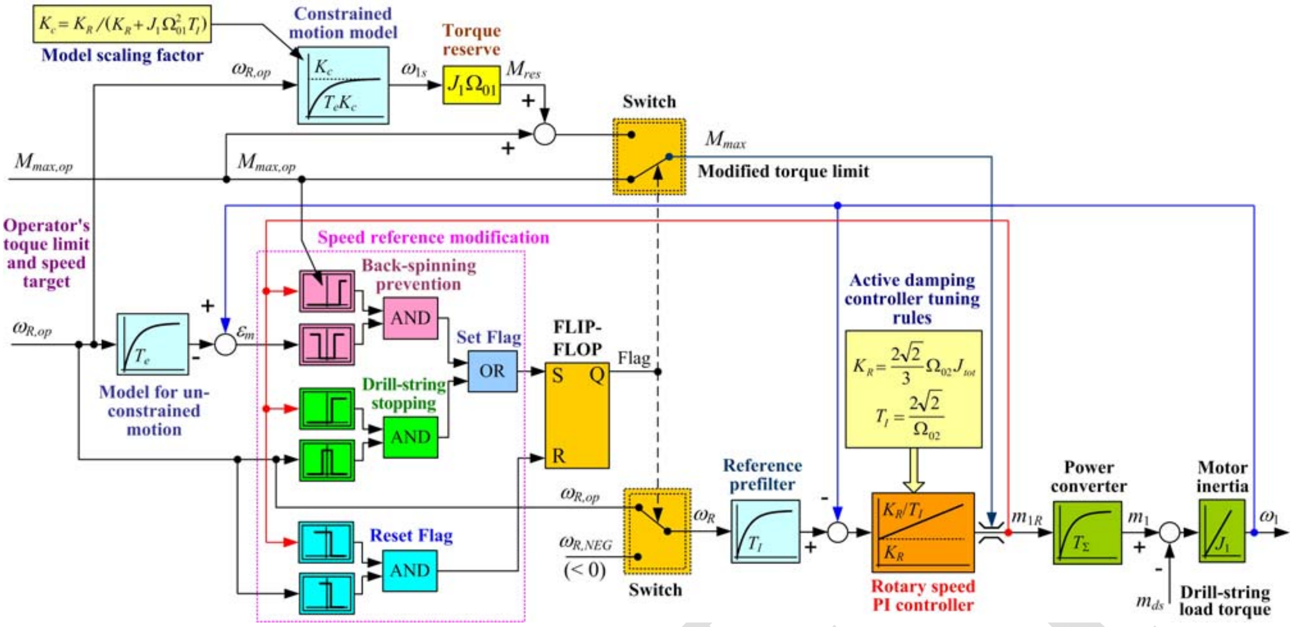

Fig. 2. Simplified representation of Soft Drive active damping system.

Field Results

The effectiveness of the proposed active damping strategy has been tested on a commercial drilling rig, wherein the comparison has been made with respect to default ("stiff") drill-string motor controller benchmark.

Figure 3a shows the comparative test results for the case of drilling with the stepwise weight-on-bit (WoB) change from 6 tons to 8 tons, wherein the active damping controller is able to suppress the torsional vibrations much better compared to the default controller. The performance of the aforementioned controllers is also compared based on the 48 hours monitoring of drilling torque and WoB by the on-site geological service, as shown in Fig. 3b. The torque response indicates that the application of active damping controller results in much smoother drill-string operation compared to the default controller (the RMS value of drilling torque perturbations is reduced by more than 50%). Moreover, this performance improvement is obtained for the approximately 15% increase of the average WoB, thereby also improving the drill-string rate of penetration (RoP).

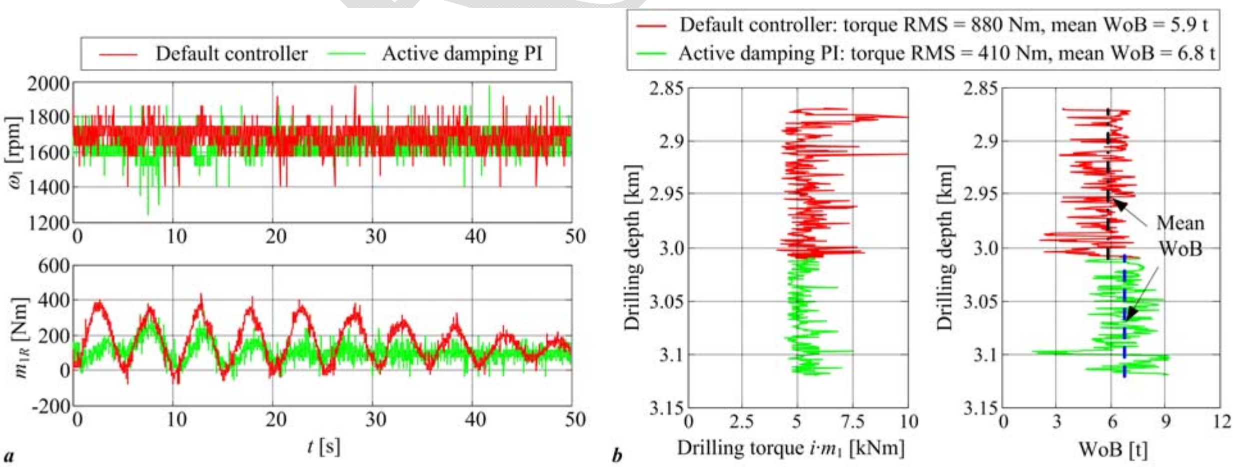

Fig. 3. Comparative field results of default ("stiff") and active damping PI controller for sudden WoB increase (a) and their long-term torque variance performance comparison (b).

Figure 4a shows the drill-string drive control field results when back-spinning phenomenon occurs. Due to the tool being stuck, the motor torque is being slowly ramped up, and it ultimately reaches the upper torque limit for motoring operation. Consequently, the drive begins to slow down until all of the motor momentum is spent to further build up the drill-string torque. This newly created torque difference suddenly accelerates the drive in the opposite direction, wherein the motor power converter switches to the braking mode. Since the power converter braking torque is typically limited to a fraction of the drive peak torque due to quite small braking power limit (typically 15% of the rated power), a sudden increase of motor deceleration occurs, thus resulting in high peak values of negative motor speed (back-spinning interval). On the other hand, when back-spinning prevention algorithm is turned on, operator's speed reference is switched to a small negative internal target value (see Fig. 2), which results in a controlled and safe drill string unwinding process, as illustrated by field results shown in Fig. 4b. Once the drill-string is sufficiently unwound, the top-drive is commanded by a zero-speed reference which safely stops the drive motion.

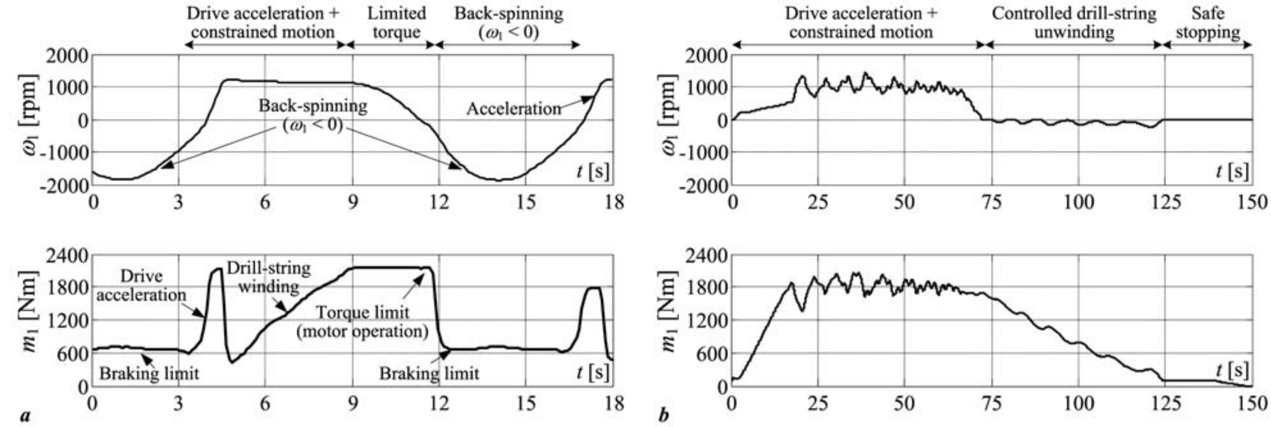

Fig. 4. Field results of drill-string drive behavior without (a) and with back-spinning prevention (b) when drill-string becomes stuck within the well-bore.

Conclusion

The presented results have shown that the Soft Drive active damping system is indeed capable of effectively suppressing the drill-string torsional vibrations encountered during drilling, thus representing a state-of-the-art solution in rotary drive control systems. Its main advantage is in its novel stuck-tool detection and back-spinning prevention system superimposed to the rotary drive speed control loop. It can facilitate safe and controlled unwinding of compliant drill-string in those drives that are equipped with braking power converter rated well below the nominal power ratings. This also makes it well suited for those rotary drives that are not equipped with emergency mechanical braking capabilities intended to arrest the undesirable drive motion under prestrained drill-string conditions.

References

[1] Jansen, J.D., van den Steen, L.: Active Damping of Self-Excited Torsional Vibrations in Oil Well Drillstrings, Journal of Sound and Vibration, 179 (1995) 4, 647-668.

[2] Runia, J. D., Dwars, S., Stulmeier, I. P. J. M.: A brief history of the Shell "Soft Torque Rotary System" and some recent case studies, In Proc. of SPE/IADC Drilling Conference, Amsterdam, Netherlands (SPE-163548-MS), 2013.

[3] Pavković, 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 Engineering Practice, 19 (2011) 8, 836–850.

[4] Serrarens, A.F.A., Van de Molengraft, M.J.G., Kok, J.J., van den Steen, L.: H-infinity Control for Suppressing Stick-Slip in Oil Well Drillstrings, IEEE Control Systems Magazine, 18 (1998) 2, 19-30.

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