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Adaptive predictor control for stabilizing pressure in a managed pressure drilling system under time-delay

Jing Zhou [a,b,*], Miroslav Krstic [c]

[a] Department of Engineering Sciences, University of Agder, 4879 Grimstad, Norway
[b] Energy Department, International Research Institute of Stavanger, 5008 Bergen, Norway
[c] Department of Mechanical and Aerospace Engineering, University of California, San Diego, CA 92093, USA

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ABSTRACT

In this paper, we address adaptive predictor feedback design for a simplified ODE drilling system in the presence of unknown parameter, disturbance and time-delay. The main objective is to stabilize the bottomhole pressure at a critical depth at a desired set-point directly. The time-delay in the transmission line of the drilling systems is considered. The stabilization of the dynamic system and the asymptotic tracking are demonstrated by the proposed predictor control, where the adaptation employs Lyapunov update law design with normalization. The proposed method is evaluated using a high fidelity drilling simulator and cases from a North Sea drilling operation are simulated. The results show that the proposed predictor controller is effective to stabilize the bottom hole pressure within the desired bound and compensate the effects of the delay in MPD. The simulation also shows that the proposed method provides good tracking, good disturbance rejection, and good compensation of time-delay.

1. Introduction

1.1. Managed pressure drilling

Managed pressure drilling (MPD) shown in Fig. 1 is defined as an adaptive drilling process used to more precisely control the annular pressure profile throughout the wellbore given by the International Association of Drilling Contractors (IADC) in [1]. The objectives of MPD are to ascertain the bottomhole pressure (BHP) environment limits and to manage the annular hydraulic pressure profile accordingly. This is typically achieved through a closed, pressurized fluid system in which flow rate, mud density, and back pressure on the fluid returns (choke manifold) are used to set and control the BHP under both static and dynamic conditions. MPD concepts come in many variants, such as Pressurized Mud Cap Drilling, Constant Bottomhole Pressure Control, Reverse Circulation, Dual-Gradient Drilling, etc.

1.2. Pressure control

A stable wellbore promotes efficient drilling and personnel safety. A destabilized wellbore can reduce or eliminate production [2]. Too low mud pressure can lead to a kick or wellbore collapse and too high mud pressure can create wellbore fracturing and losses as shown in Fig. 2. Preventing these costly stability problems requires accurate pressure control. The main objective is to precisely control BHP throughout the wellbore continuously while drilling, *i.e.* to maintain the pressure in the wellbore above the pore or collapse pressure and below the fracture or sticking pressure. Usually, this amounts to stabilizing the BHP at a critical depth at a desired set-point directly, *i.e.* either at a particular depth where the pressure margins are small, or at the drill bit where conditions are the most uncertain.

Constant BHP control is a challenging task during well drilling, due to the complex dynamics of the multiphase flow potentially consisting of drilling mud, oil, gas and cuttings. By allowing manipulation of the topside choke and pumps, MPD provides a means of quickly affecting pressure to counteract disturbances, and several control schemes are found in the literature. State-of-the-art solutions typically employ

* Corresponding author at: Department of Engineering Sciences, University of Agder, 4879 Grimstad, Norway. Tel.: +47 46695089.
E-mail address: jingzhou@ieee.org (J. Zhou).

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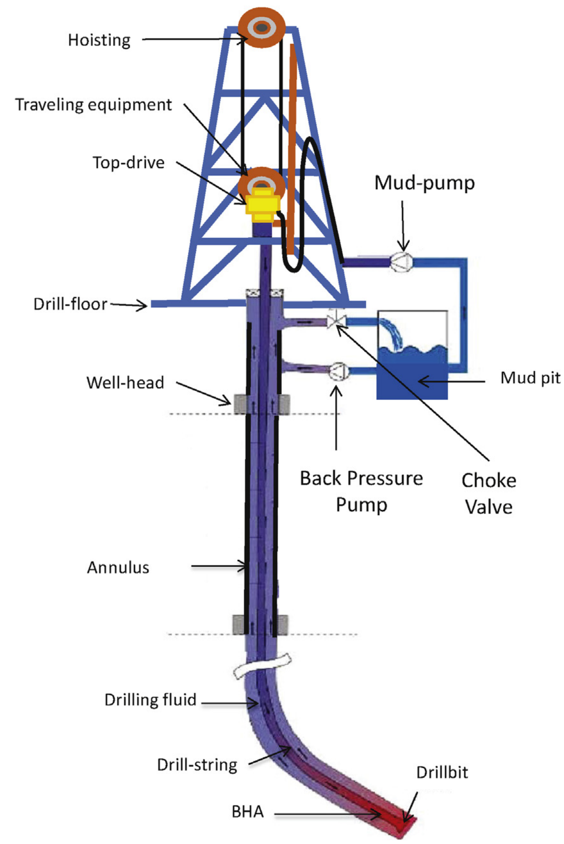

Fig. 1. MPD system.

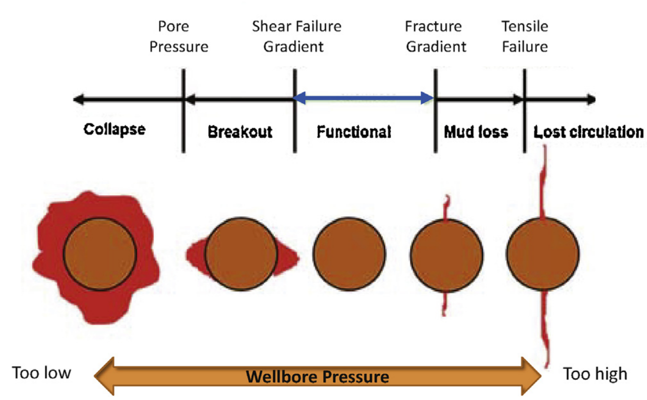

Fig. 2. Well integrity.

conventional Proportional Integral (PI) control applied to the choke in drilling process in [3–6]. There are significant drawbacks using PI control. One is that the control system based on conventional PI control will react slowly to pressure changes and flowrate changes, which results from movements of the drill string and from the draw-down test or pipe connection. Another drawback is the uncertainty in the pressured mud system, due to uncertainties in the friction and mud compressibility parameters in both the drill string and annulus.

A lot of effort has been put into developing advanced complicated models that capture all aspects of the drilling fluid hydraulics. However, a main drawback is the resulting complexity of these models, which require expert knowledge to set up and calibrate, making it a high-end solution. The complexity is also increased by the fact that many of the parameters in such models are uncertain and possibly slowly changing, which implies that they would need to be tuned when operating conditions change. In order to reduce the complexity, a simplified low order model for control and estimation of the BHP is used in [7–12], where ordinary differential equations (ODE) are used to capture the dominant phenomena of the drilling system. Based on this low order ODE model, several control schemes are found in the literature, such as [9,10,13–17]. Model based control was also presented for directional drilling systems in [18,19]. Research on BHP estimation in MPD has been conducted in our articles [9,10,13,15,20], where adaptive observers are used. The model predictive control has been studied in [17] for in DGD operation. In [14–16,21], an automatic switch control scheme is developed for kick attenuation and pressure regulation and when there is an influx in MPD. Kick detection and control has also been studied in [22–24]. However the time delay problem is not considered in these papers.