Pressure Regulation and Kick Attenuation with Wired Drill Pipe Technology in Managed Pressure Drilling

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While advanced process control and optimization has been extensively applied to chemicals and downstream refining [1, 2], it is still relatively unexplored and immature in drilling automation and in many areas of upstream production [3]. The challenge is that exploration and production is progressively moving into more extreme environments with narrow pressure margins as productivity declines from existing wells. If not managed properly, these extreme environments can lead to damaged formations and loss of well productivity or worse yet, safety incidents and loss of human life. The goal of this paper is to introduce an efficient automated control that maintains the pressure within acceptable window while at the same time detects and attenuates the unexpected gas influx (termed as kick) in managed pressure drilling. To achieve this, a novel formulation for pressure control along a drill-string is presented by leveraging a new wired drill pipe telemetry network for high-speed and distributed sensing using a nonlinear model predictive controller and moving horizon estimator.

A wired pipe telemetry network offers high speed two way data communication between the surface and downhole sensors [4, 5]. In this technology sensors are positioned at various points along the drill string. Integrating the wired pipe technology into the control and observer structures will make it possible to control the pressure along the drill string as well as the downhole pressure directly and therefore more precisely. Mud pulse telemetry controllers and observers use topside measurements to estimate the friction factor and downhole pressure but do not rely on direct pressure measurements for control.

A finite horizon nonlinear model predictive controller (NMPC) for pressure is proposed using mud pump flow rate and choke valve opening as manipulated variables. The predictive ability of NMPC makes it possible to anticipate future events and take actions beforehand to avoid some undesired behaviors [6]. NMPC used in this research utilizes a nonlinear low order model developed by Stamnes et al [7], which is further modified to capture the main hydraulic dynamics of a drilling process equipped with a wired pipe telemetry network.

The friction factors (f_a) and densities (ρ_a) in the annulus are unmeasured and unknown due to the changes in temperature and mud properties in the annulus, etc [8]. To find predicted values, a nonlinear moving horizon estimator is developed which is based on optimization methods [9] and uses both annular pressure values as well as surface measurements in data reconciliation. The unique feature of the developed estimator is that it is able to estimate separate density and friction factors for each drill pipe segment which in turn enhances the controller performance. The observer used in the current research uses active set and interior point nonlinear optimization methods to find the estimated values. In this way it is possible to use constraints (e.g. physical limitations of equipment, rate of disturbance change, etc.) in designing the observer. This is an advantage over Kalman filter and adaptive observer methods which are unconstrained methods.

The performance of a wired pipe technology based controller is evaluated in terms of how fast and consistently it responds to unwanted gas influx during a simulated kick event. The difference in flow rate through the drill bit and annulus, change in density, and change in friction factor are used to detect kicks.

The controller takes appropriate immediate action for attenuating the kick by adjusting the choke valve opening and mud pump flow rate while circulating out the gas. The kick attenuation behavior of a wired pipe based controller and a mud pulse based controller are compared with quantitative performance results. The proposed controller uses multiple pressure sensors along the drill annulus allowing it to maintain a distributed pressure profile. Therefore, it has less reaction time to unexpected gas influx and improved pressure control performance compared with the controller based on mud pulse telemetry.

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