NTNU

Innovation and Creativity

Adaptive Observer Design for the Bottomhole Pressure of a Managed Pressure Drilling System
CDC - Cancun

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Glenn-Ole Kaasa, Ole Morten Aamo

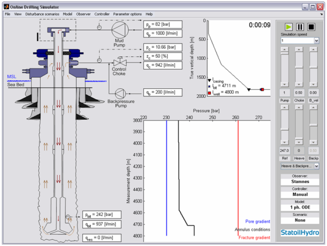
Department of Engineering Cybernetics

10 Dec. 2008

StatoilHydro

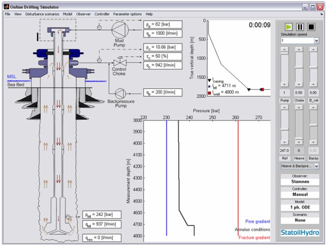
Outline

Outline



— Drilling 101

Outline



— Drilling 101

— System Model

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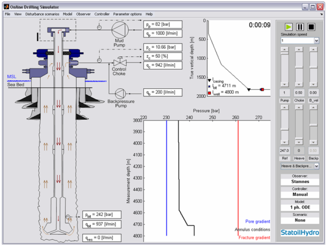
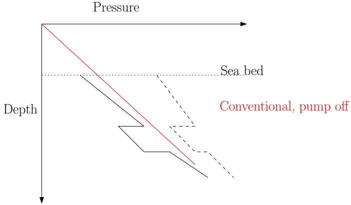
- Drilling 101
- System Model
- Observer Design





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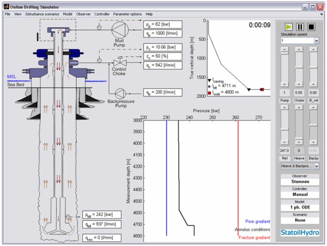

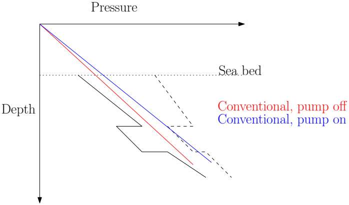

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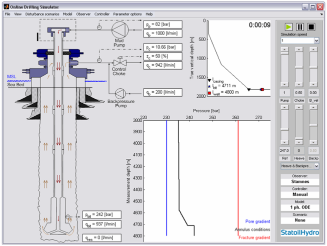
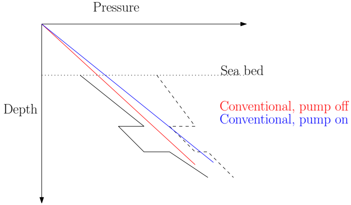


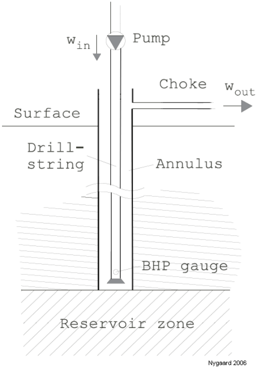
- Drilling 101
- System Model
- Observer Design
- Simulation Results



Drilling 101

Drilling 101

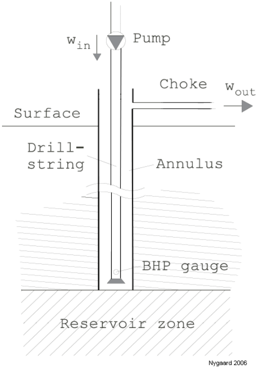
— Conventional Drilling

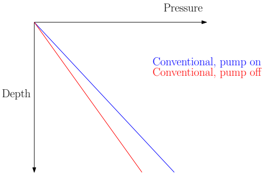


Drilling 101

— Conventional Drilling

$$P_{ann} = P_{fric} + P_{hydro}$$
$$P_{ann} = \text{Annular pressure}$$
$$P_{fric} = \text{Friction pressure}$$
$$P_{hydro} = \text{Hydrostatic pressure}$$





Drilling 101

- Conventional Drilling
- Managed Pressure Drilling (MPD)

$$P_{ann} = P_{fric} + P_{hydro} + P_{choke}$$
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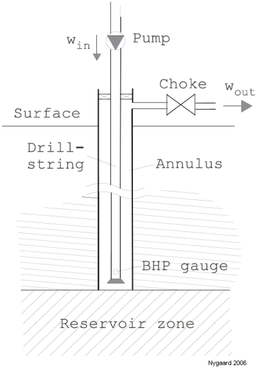

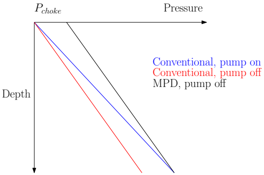

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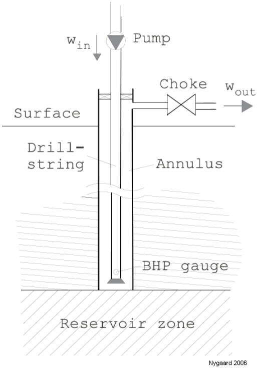
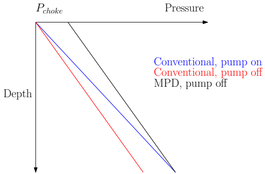
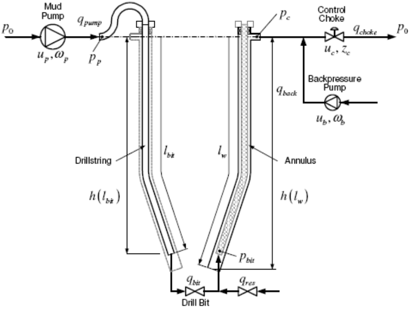


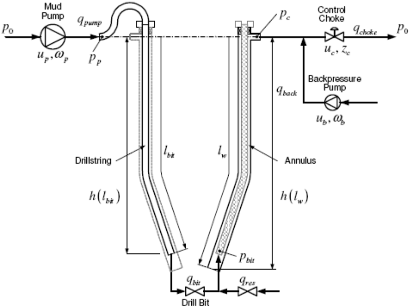


Model- Main Assumptions



Model- Main Assumptions

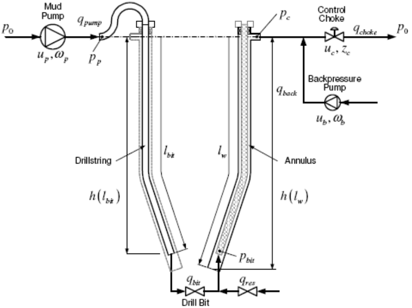
— 1. phase, effect of gas in well included in density and effective bulk modulus



Model- Main Assumptions

— 1. phase, effect of gas in well included in density and effective bulk modulus

— Rigid flow in momentum balance



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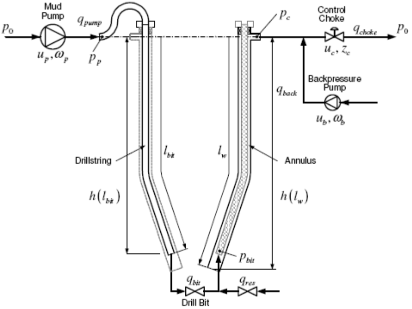
- Rigid flow in momentum balance
- Turbulent flow regime



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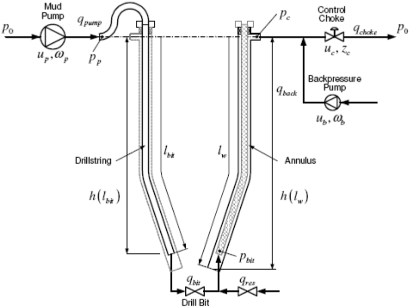
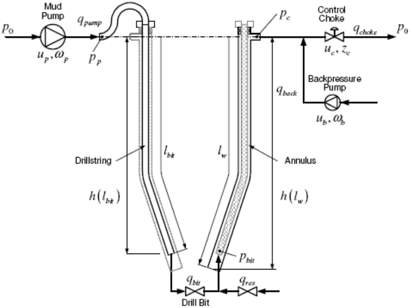
- 1-dimensjonal flow

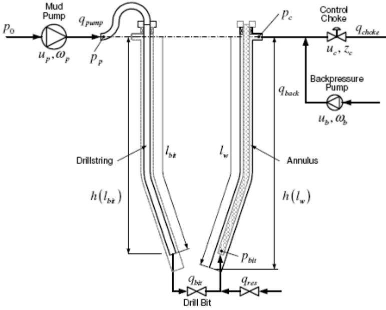


Model- Main Assumptions

- 1. phase, effect of gas in well included in density and effective bulk modulus
- Rigid flow in momentum balance
- Turbulent flow regime
- 1-dimensjonal flow
- Isothermal conditions



Model



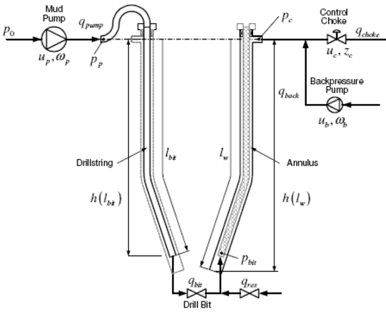
p=[bar], V=[m^3], q=$\left[\frac{m^3}{s}\right]$

β=[bar], h=[m], g=9.81$\left[\frac{m}{s^2}\right]$

F=friction factor, ρ=$\left[\frac{kg}{m^3}\right]$

Model

$$\frac{V_a}{\beta_a}\dot{p}_c + \dot{V}_a = q_{bit} + q_{back} + q_{res} - q_{choke}$$



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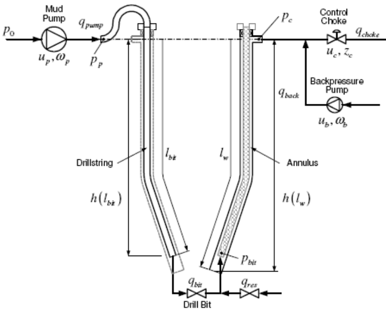
$$\frac{V_d}{\beta_d}\dot{p}_p = q_{pump} - q_{bit}$$



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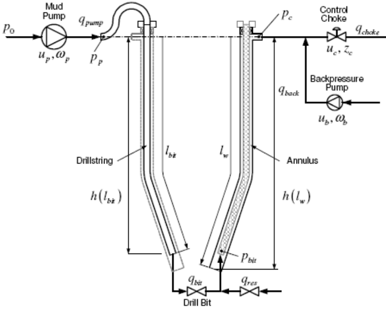
$$M\dot{q}_{bit} = p_p - p_c - (F_d + F_a)|q_{bit}|q_{bit} + (\rho_d - \rho_a) g h_{bit}$$



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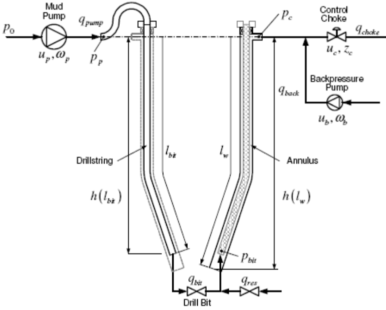
F=friction factor, ρ=$\left[\frac{kg}{m^3}\right]$

$$M = M_d + M_a$$

$$M_d = \rho_d \int_0^{l_{bit}} \frac{1}{A_d(x)} dx,$$

$$M_a = \rho_a \int_0^{l_w} \frac{1}{A_a(x)} dx$$

Model



$$\frac{V_a}{\beta_a}\dot{p}_c + \dot{V}_a = q_{bit} + q_{back} + q_{res} - q_{choke}$$

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$$M\dot{q}_{bit} = p_p - p_c - (F_d + F_a)|q_{bit}|q_{bit} + (\rho_d - \rho_a)gh_{bit}$$

$$p_{bit} = \begin{cases} p_c + M_a\dot{q}_{bit} + F_a|q_{bit}|q_{bit} + \rho_a g h_{bit} \\ p_p + M_d\dot{q}_{bit} - F_d|q_{bit}|q_{bit} + \rho_d g h_{bit} \end{cases}$$

p=[bar], V=[m^3], q=$\left[\frac{m^3}{s}\right]$

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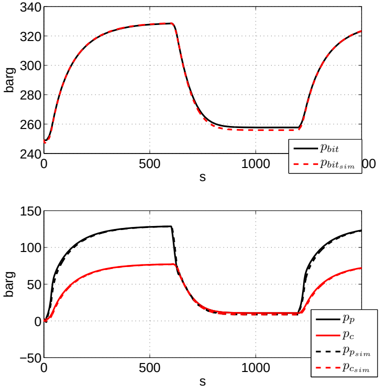

Figure: Model fitted to WeMod

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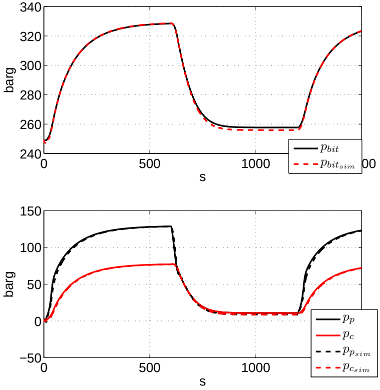


Figure: Model fitted to WeMod

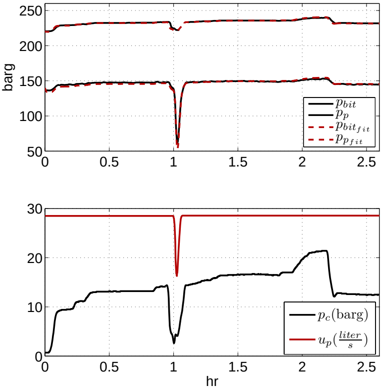
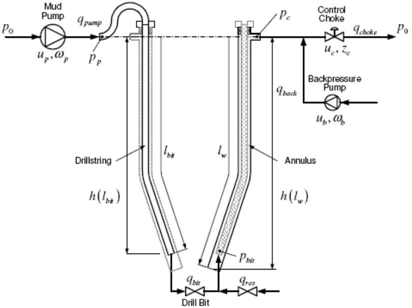


Figure: Model fitted to data

Observer Design - Assumption

— Measure top-side pressures and flow through main pump



Observer Design - Assumption

- Measure top-side pressures and flow through main pump
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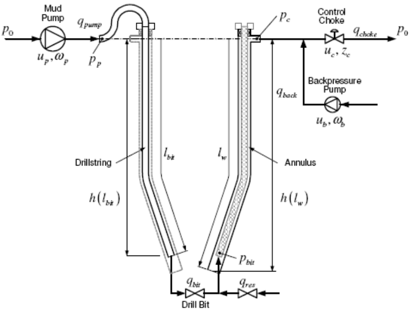
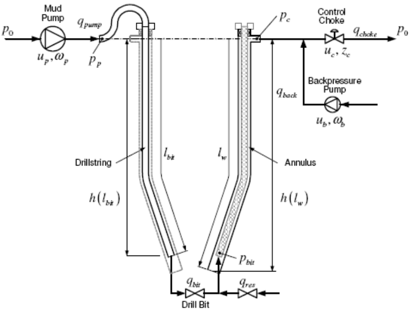


Observer Design - Assumption

- Measure top-side pressures and flow through main pump
- measure/know the geometry of the well
- all parameters except friction and density in annulus known



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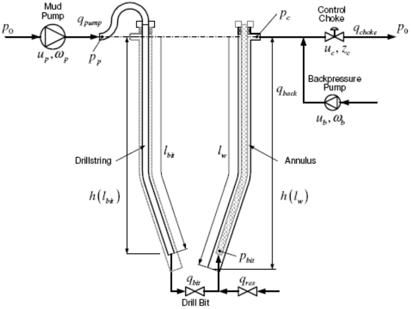
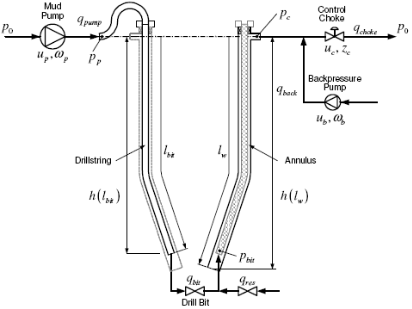


Observer Design - Assumption

- Measure top-side pressures and flow through main pump
- measure/know the geometry of the well
- all parameters except friction and density in annulus known
- $q_{res} = 0$
- $q_{bit} > 0$, in reality $q_{bit} \geq 0$



Observer Design - Model

Same model, unkown friction and density

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$$\dot{p}_p = -a_1 q_{bit} + b_1 u_p$$

$$a_1 = \frac{\beta_d}{V_d}, \qquad b_1 = a_1$$

Observer Design - Model

Same model, unkown friction and density

$$\dot{p}_p = -a_1 q_{bit} + b_1 u_p$$
$$\dot{q}_{bit} = a_2(p_p - p_c) - \theta_1 |q_{bit}| q_{bit} + \theta_2 v_3$$

$$a_1 = \frac{\beta_d}{V_d}, \qquad b_1 = a_1$$
$$a_2 = \frac{1}{M}, \qquad \theta_1 = \frac{F_a + F_d}{M}$$

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Define $\xi = q_{bit} + l_1 p_p$. l_1 is a tuning gain.

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A state estimator for q_{bit}

$$\dot{\widehat{\xi}} = -l_1 a_1 \widehat{q}_{bit} - \widehat{\theta}_1 |\widehat{q}_{bit}| \widehat{q}_{bit} + \widehat{\theta}_2 v_3 + a_2 (p_p - p_c) + l_1 b_1 u_p$$

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Error dynamics for $\tilde{\xi} = q_{bit} - \widehat{q}_{bit}$

$$\dot{\tilde{\xi}} = -l_1 a_1 \tilde{\xi} - \theta_1 (|q_{bit}| q_{bit} - |\widehat{q}_{bit}| \widehat{q}_{bit}) + \tilde{\theta}^T \phi(\widehat{q}_{bit}, v_3)$$

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Define $\xi = q_{bit} + l_1 p_p$. l_1 is a tuning gain. Dynamics for ξ

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$$\phi(\widehat{q}_{bit}, v_3) = \left[-|\widehat{q}_{bit}| \widehat{q}_{bit}, \ v_3\right]^T$$

Observer Design - Lyapunov Analysis

Lyapunov type analysis

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- $V = \frac{1}{2}\tilde{\xi}^2 + \frac{1}{2}\tilde{\theta}^T\Gamma^{-1}\tilde{\theta}$

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Lyapunov type analysis

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- Using Barbălat's lemma we get $\lim_{t \to \infty} \tilde{\xi} = \lim_{t \to \infty} \tilde{q}_{bit} = 0$

Observer Design - Lyapunov Analysis

Lyapunov type analysis

- $V = \frac{1}{2}\tilde{\xi}^2 + \frac{1}{2}\tilde{\theta}^T\Gamma^{-1}\tilde{\theta}$
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- $\tilde{q}_{bit} \to 0$ og $\tilde{\theta}^T\phi \to 0$ enables us to get an estimate $\hat{p}_{bit} \to p_{bit}$

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Observe that $\tilde{\sigma} = \tilde{\theta}$ og $\dot{\tilde{\theta}} = \dot{\tilde{\sigma}} = l_1 a_1 \frac{\partial\eta}{\partial\widehat{q}_{bit}}\tilde{q}_{bit}$.

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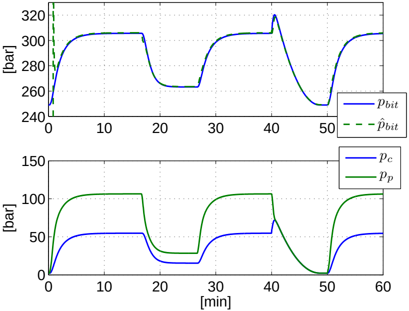
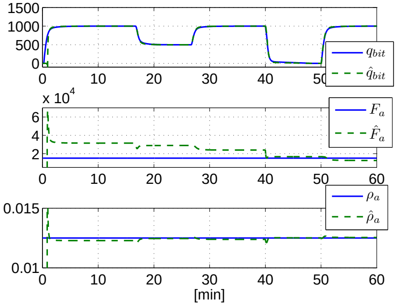
Solve pde: $l_1 a_1 \frac{\partial\eta}{\partial\widehat{q}_{bit}} = -\Gamma\phi\tilde{\xi}$

Simulation - WeMod



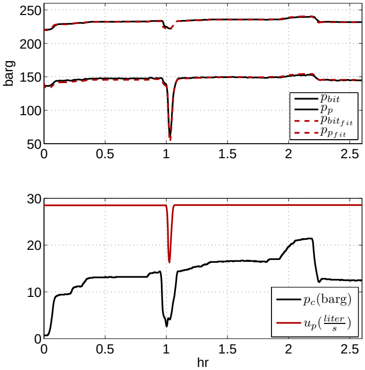


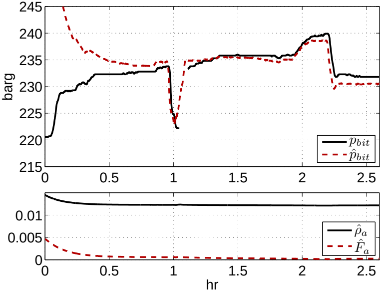
Initial conditions:

$\hat{q}_{bit}(t_0) = u_p(t_0)$, $\hat{\rho}_a(t_0) = 2\rho_a$,

$\hat{F}_a(t_0) = 3F_a$, $t_0 = 50s$

Simulation - Data





Initial conditions:

$\hat{q}_{bit}(t_0) = u_p(t_0)$, $\hat{\rho}_a(t_0) = 1.2\rho_a$,
$\hat{F}_a(t_0) = 1.5F_a$

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Thank you!

Norwegian University of
Science and Technology