Kelda Drilling Controls AS
Hydrovegen 6
3933 PORSGRUNN

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Open

Homework assignment – Identification of parameters of hydraulic model

The following document describes the main homework assignment in the course

- *TK17 - System Identification*.

The objective of the assignment is to learn practical aspects of system identification through a relevant case study.

A lecture on practical aspects of offline parameter estimation with focus on the particular case study was given September 24th 2015.

Best regards,

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Identification of parameters in hydraulic model

1 Task description

The objective of the assignment is to identify the parameters of a hydraulic model using data from a real well. In particular, the goal is to achieve the best possible fit of the downhole pressure p_{dh} to all the experimental downhole data provided.

The model structure and parameters are described in the following subsections.

To make the task manageable as a home assignment in this course, some practical aspects have been simplified, such as:

- Deriving a model structure
- Selecting parameters possible to estimate
- Processing of data from the original source files
- Selection of experiments to include as basis for parameter estimation

1.1 Case study: Managed Pressure Drilling

The main application considered is downhole pressure control during drilling operations, known as *Managed Pressure Drilling*. A schematic is given in Figure 1.

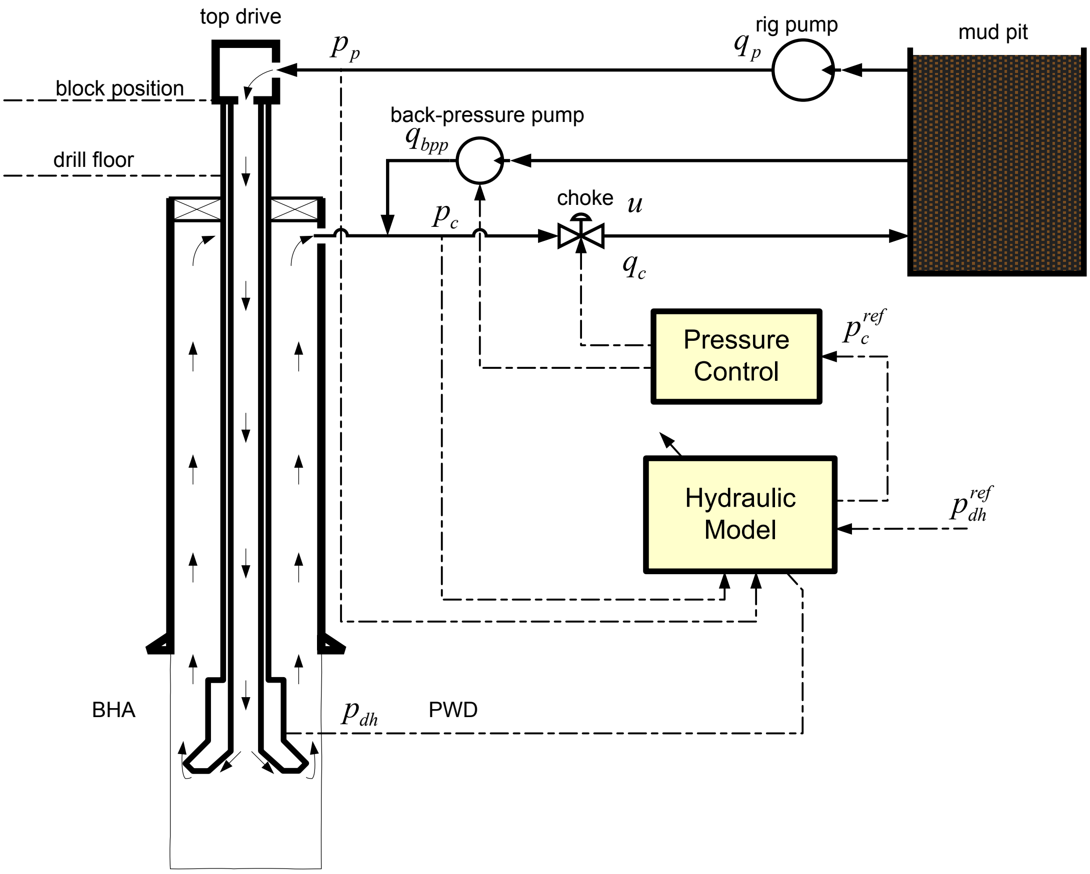

Figure 1 - Schematic of control system for Managed Pressure Drilling.

1.2 Model structure and parameters

The model is used as basis for advanced control system design, in particular

- Observer design for estimation of the downhole pressure
- Model-based control design
- Online model calibration, and
- Fault-detection.

It is vital that such a model is *fit-for-purpose*, that is, it must be sufficiently simple to enable parameter estimation, and ensure robustness of the resulting control system algorithms. This means that any unneccessary complexity should be removed so that the model includes only the dominating dynamics and properties of the system which is relevant for controller and observer design. This is the case of the model considered in this home assignment. Additional details about the modelling can be found in the reference material provided with the assignment.

The dynamics of the model can be expressed as

$$
\begin{aligned}
&\frac{V_d}{\beta_d}\frac{dp_p}{dt} = q_p\left(u_p\right) - q \\
&\frac{V_a}{\beta_a}\frac{dp_c}{dt} = q + q_{bpp}\left(u_{bpp}\right) - q_c\left(p_c, z_c\right) \\
&M\frac{dq}{dt} = \begin{cases} p_p - p_c - f_d\left(q\right) - f_a\left(q\right) + \rho_d g h_d - \rho_a g h_a, & q > 0 \\ 0, & q = 0 \end{cases}
\end{aligned}
\tag{0.1}
$$

where the downhole pressure p_{dh} is the output equation which can be given as

$$p_{dh} = p_c + f_a\left(q\right) + \rho_a g h. \tag{0.2}$$

Remark: There is a one-way valve in the drillstring which prevents negative flow q in the drill string. This is modelled by a piecewise definition of the dynamics for q in (0.1). This will become active when the main pump flow is zero (q_p = 0), and the backpressure pump q_{bpp} is ramped up. This is the case in data set #3.

1.2.1 States and inputs

In the model, the states p_p, p_c and q are pump pressure, choke pressure and mean flow rate, respectively.

The choke flow $q_c(z_c)$ is the main manipulated input, where z_c is the actuator position which determines the opening of the choke. The actuator position z_c is controlled by a low-level control loop which attempts to track the command input u. In most cases, this actuator dynamics is negligible fast, so that we can take $z_c = u$. However, in the data set provided, you may notice that this is not always the case.

The pump flows q_p and q_{bpp} are controlled inputs, which in this case can be viewed as measured disturbances. The function arguments u_p and u_{bpp} represents the actual manipulated inputs for these pumps, and the actuator dynamics have been neglected.

1.2.2 Parameters

The parameter g is the gravitational acceleration g = 9.8 m/s^2, and h is the vertical downhole depth at the location of interest. The depth of the bit in the experimental data is h = 1730 m, and $h_d \approx h_a = h$.

The parameters V_d, V_a, β_d, β_a, M, ρ_d and ρ_a are unknown parameters to be estimated.

A reasonable estimate of M can be taken as 10^9 kg/m^4 = Pa s^2/m^3.

Remark: *It may be numerically advantageous to simulate the model using pressures in bar rather than Pa. Note that the units of the parameters must then be updated correspondingly.*

1.3 Friction characteristics

The functions $f_d(q)$ and $f_a(q)$ describe the frictional pressure drop as function of flow through the drill string and annulus, respectively.

A simple parametrization can be given as

$$\begin{aligned} f_d(q) &= C_d q + D_d q^2 \\ f_a(q) &= C_a q + D_a q^2 \end{aligned} \tag{0.3}$$

where C_d, D_d, C_a, D_a are unknown parameters.

Typically, the frictional pressure drop in the drillstring is dominated by turbulent flow, while the frictional pressure drop in the annulus is dominated by laminar flow. This means that in most cases we can take $C_d = D_a = 0$ without sacrificing much accuracy.

1.4 Choke characteristics

The function $q_c(p_c, z_c)$ describes the flow through the choke, and can be given as

$$q_c(p_c, u_c) = \sqrt{(p_c - p_{c0})} g_c(z_c). \tag{0.4}$$

Here, $g_c(z_c)$ is the nonlinear input characteristics of the choke as function of actuator position z_c, and p_c and p_{c0} are the pressures, upstream and downstream the choke, respectively.

Part of the homework assignment is to formulate a parametrization of the nonlinear input characteristic $g_c(z_c)$ in the parameter-linear form

$$g_c(u) = \phi_c(u)^T \theta_c \tag{0.5}$$

and subsequently estimate its parameters θ_c.

In case of difficulties with this task, a look-up table of an approximate choke characteristic is provided in the data set in the form of vectors Z_c and G_c.

1.5 Measurements from drilling operations

Three data sets from the commissioning of an offshore drilling operation has been selected for this homework assignment. These data sets are provided in the file *TK17_SysId_CaseStudy.mat*, which must be loaded in matlab. The three data sets are there given as three separate structure arrays, and should be self-explanatory.

In the data sets, all the states and inputs of the model (0.1) are measured, except for the flow state q. It is a common practical problem in system identification, that certain states are not possible to measure. In this case, there are several ways to handle this, and we have therefore left this as a task to solve as part of the homework assignment.

1.5.1 Data set #1

This data set is given in the structure array LOG1.

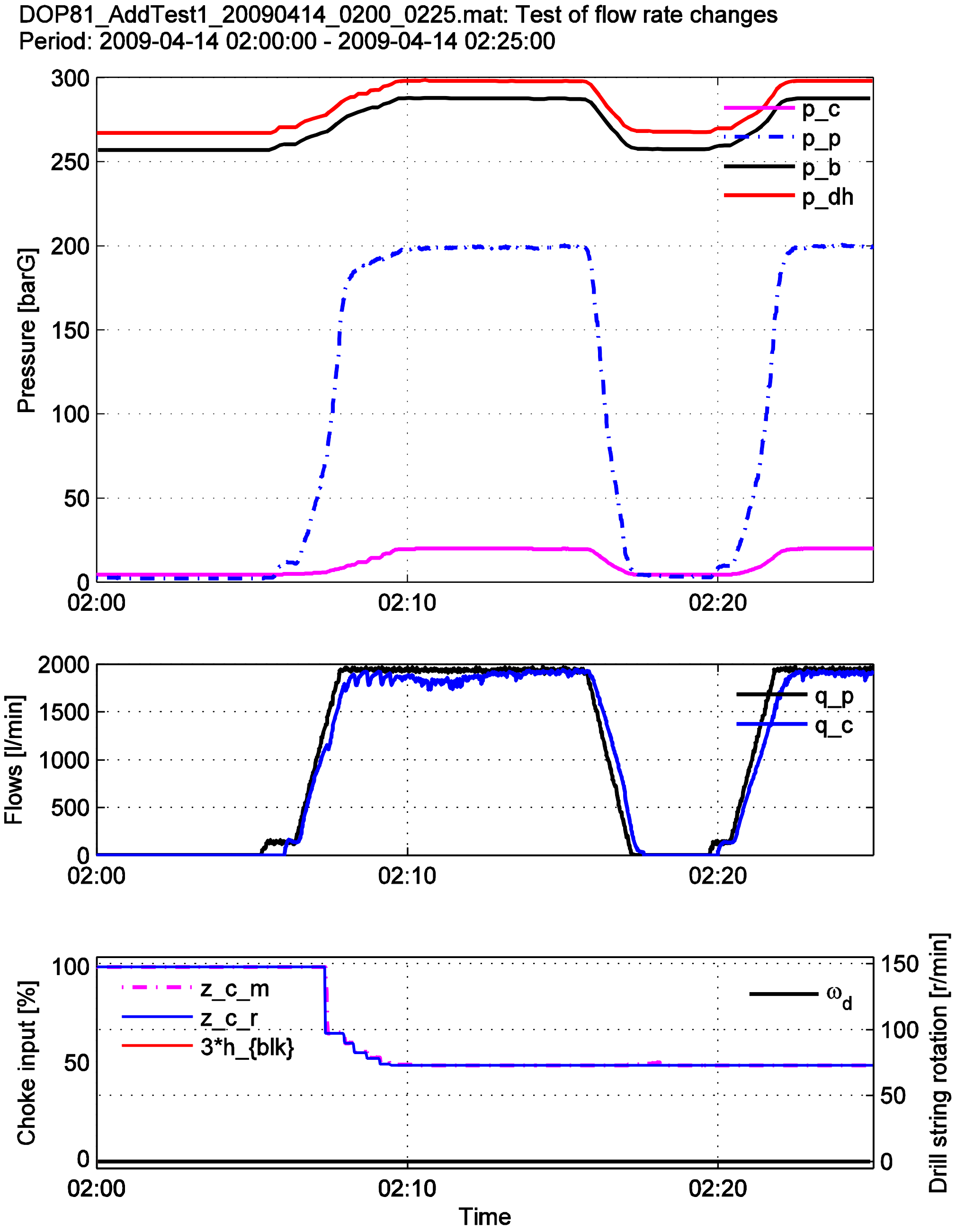

Figure 2 - Plot of data set #1.

1.5.2 Data set #2

This data set is given in the structure array LOG2.

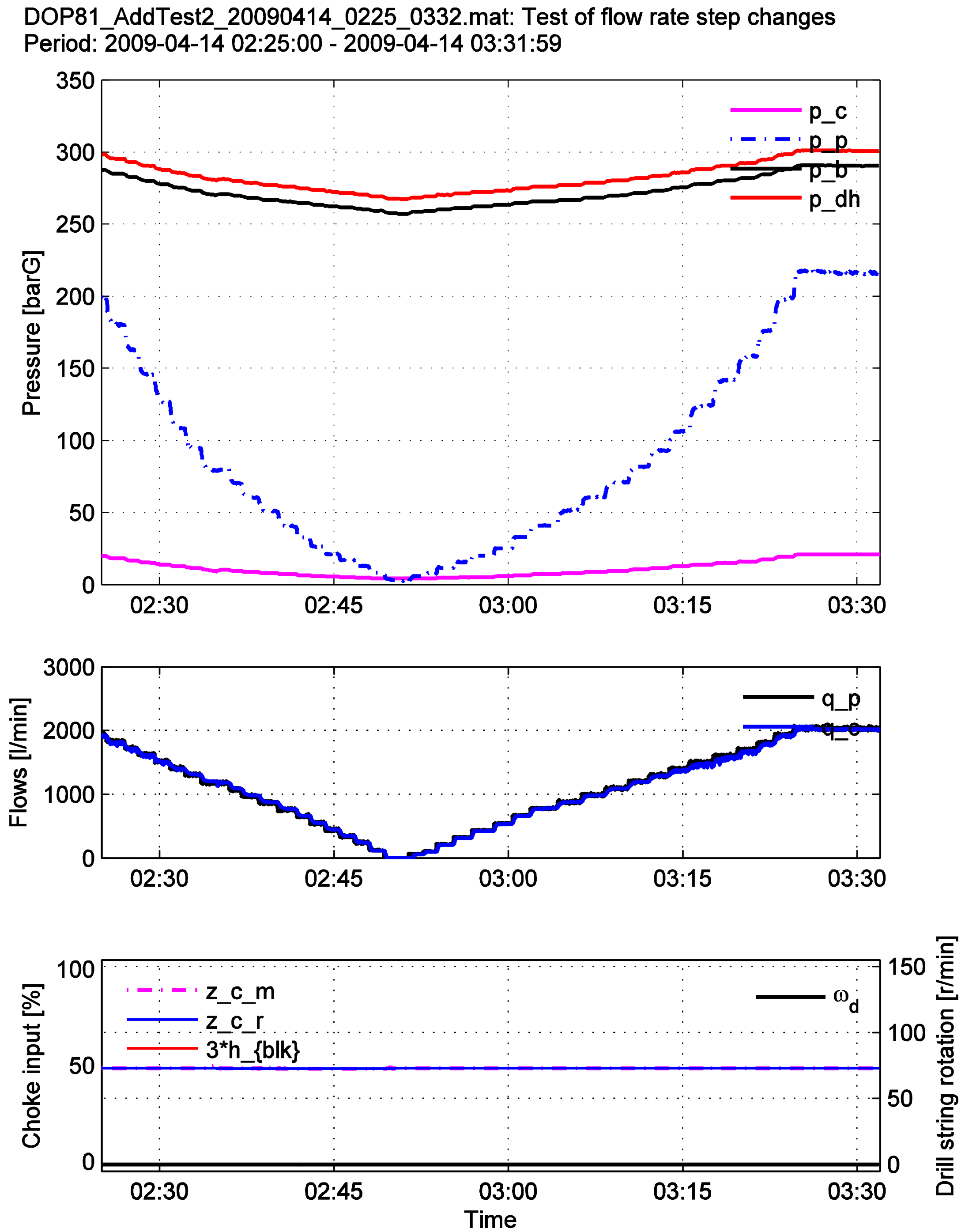

Figure 3 - Plot of data set # 2.

1.5.3 Data set #3

This data set is given in the structure array LOG3.

Remark: The experimental data after time 06:30 has been subject to system changes not described in this note, and can thus be disregarded in the analysis.

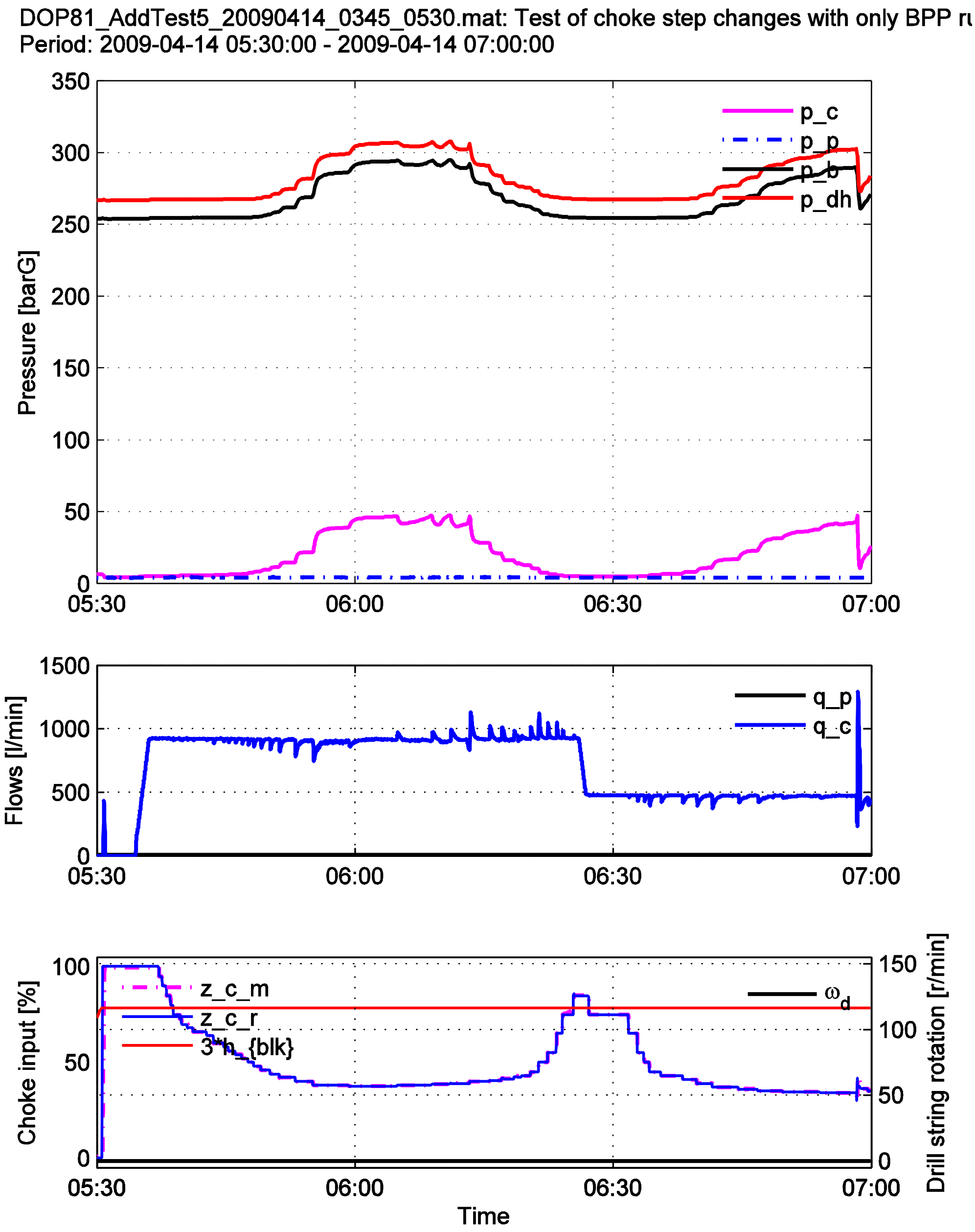

Figure 4 - Plot of data set # 3.

Remark: Note that in data set #3, there is no flow from the main pump (i.e. q_p = 0), and only q_{bpp} provides the flow through the choke (q_c). This means that the model (0.1)–(0.2) reduces to

$$\frac{V_a}{\beta_a}\frac{dp_c}{dt} = q_{bpp} - q_c\left(p_c, z_c\right) \tag{0.6}$$

$$p_{dh} = p_c + \rho_a g h. \tag{0.7}$$

1.6 Reference material

More detailed information and details on the case study and application of the model can be found in the following papers which are provided as background material:

- Lecture presentation given at NTNU as part of *TK17 - System Identification*
  - Lecture - TK17 System Identification.pdf
- Derivation of model
  - Kaasa2011a - Intelligent estimation of downhole pressure using simplified hydraulic model - SPE-143097.pdf
- Control system design
  - Godhavn2011 - Drilling seeking automatic control solutions.pdf
- Observer design
  - Stamnes2011b - Adaptive Estimation of Downhole Pressure for Managed Pressure Drilling Operations.pdf
  - Stamnes2011a - Nonlinear estimation with application to drilling - PhD thesis.pdf
- Modelling static nonlinearities
  - Appendix A: Kaasa2004 - Nonlinear output-feedback control applied to pneumatic clutch actuation in heavy-duty trucks.pdf