University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET575 Automated Drilling and Modeling

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TIME: 4 hours

AID: Approved calculator

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Question 1 Drilling automation

Figure 1 shows a schematic of a drilling topside control system. In the figure, PLC stands for programmable logic controller.

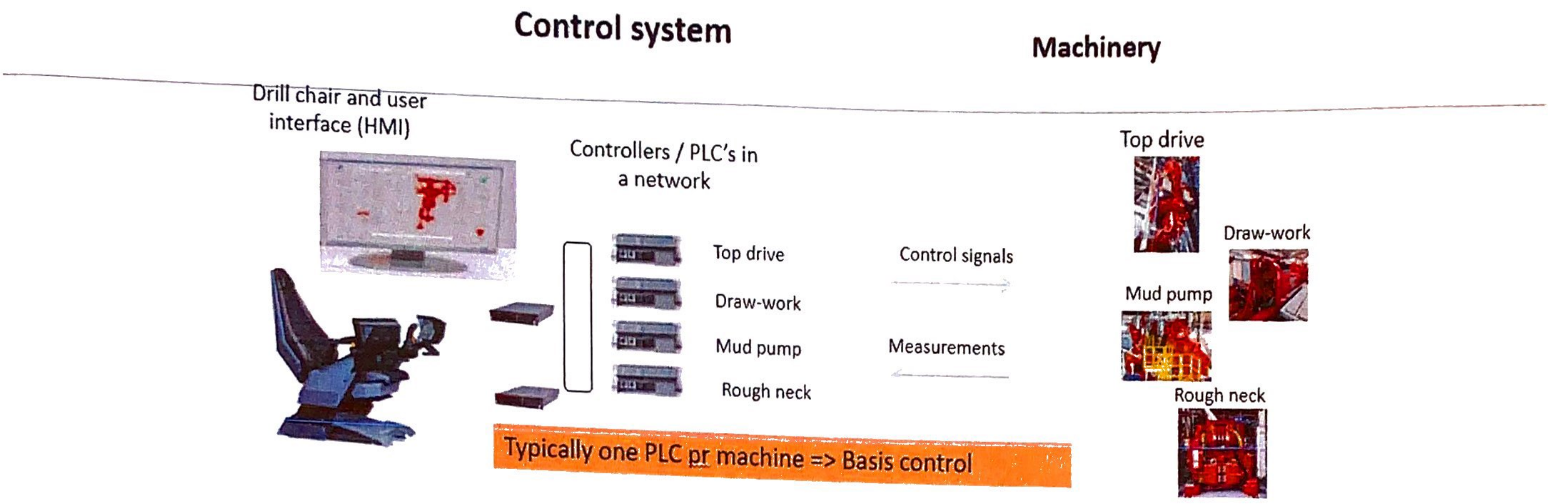


Figure 1 Drilling control system

Please answer the following questions.

Q1.1. Describe how the drilling control system shown in Figure 1 works.

Q1.2. List the important automation tools used in such system and describe their functions respectively.

Q1.3. The automation level is divided into three ones: manual, semi-autonomous and autonomous level. Please describe the differences among them. For the system given in Figure 1, does it belong to

(A) Manual level?
(B) Semi-autonomous level?
(C) Autonomous level?

State your reason.

Question 2 Drilling fluids

The structure of the drilling fluid property evaluation system is shown in Figure 2. Differential pressure sensors are installed on the pipe in order to automatically evaluate the drilling fluid's density and viscosity. DP1 in the figure is the differential pressure between pressures P1 and P2, or

$$DP_1 = P_2 - P_1.$$

Where sensors 1, 2, 3 and 4 are installed on the vertical pipe with the inclination angle being 0^o. The values of the parameters involved in the calculation are given in Table 1. It assumes that the fluid's density does not vary with flow rates. Both the density and the viscosity are uniform in the whole system. The fluid is a Newtonian fluid. The flow direction is given in the figure.

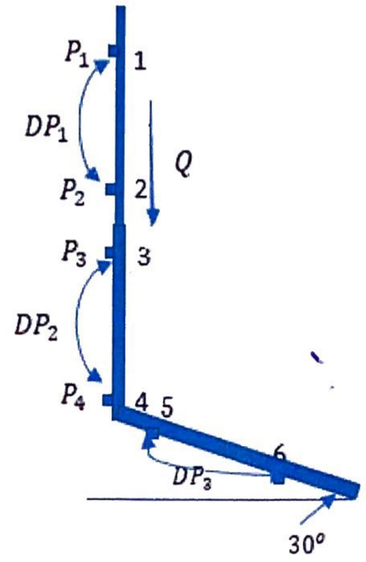


Figure 2 Structure of the system

Description	Notation	Values	Unit
Acceleration of gravity	g	9.8	m/s^2
Inner diameter of the pipe between points 1 and 2	D_1	0.02	m
Inner diameter of the pipe between points 3 and 4	D_2	0.04	m
Inner diameter of the pipe between points 5 and 6	D_2	0.04	m
Length between points 1,2	l	4	m
Length between points 3,4	l	4	m
Length between points 5,6	l	4	m
Pipe roughness	ε	0	

Table 1 Parameters' values

The measured differential pressures (DP1) with respect to flow rates (Q) are listed in Table 2. The situation when the flow rate is 0 means that there is no circulation and the pipe is full of the fluid.

Flow rate (Q) (m^3/s)	DP1 (Pascal)
0	39200
30/60000 (0.0005)	33200

Table 2 Differential pressures vs flow rates

Q2.1 Calculate the density (ρ) and the viscosity (μ) of the fluid based on Table 1 and Table 2 and fill Table 3.

Flow rate (Q) (m^3/s)	density (ρ) of fluid (kg/m^3)	viscosity (μ) of fluid (Pa.s)
30/60000 (0.0005)		

Table 3 Fluid properties vs flow rate

Q2.2 Calculate the differential pressure between points 3 and 4 (DP2), where DP2 is the differential pressure between pressures P3 and P4, or

$$DP_2 = P_4 - P_3.$$

And calculate the differential pressure between points 5 and 6 (DP3), where DP3 is the differential pressure between pressures P5 and P6, or

$$DP_3 = P_6 - P_5.$$

Where sensors 5 and 6 are installed on the inclined pipe with the angle being 30^o, see Figure 2. Then fill Table 4.

Flow rate (Q) (m^3/s)	DP2 (Pascal)	DP3 (Pascal)
30/60000 (0.0005)		

Table 4 Differential pressure vs flow rate

Question 3 Modeling and Simulink

Q3.1 What is the difference between a static and dynamic model?

Q3.2 Tank model

A tank is provided to store the feed liquid. Assume that the plant equipment is operated continuously. There is a mixer installed in the tank to mix the liquid such that the density of the liquid in the tank is uniform. The situation is sketched in Figure 3, with the following notations:

Inlet A injecting heavy mud with density ρ_h; flow rate is defined as q_h;

Inlet B injecting light mud with density ρ_l; flow rate is defined as q_l;

The total flow rate of liquids injected from A and B is q_{ab} or $q_h + q_l = q_{ab}$;

Inlet C injecting the mud that is circulated back from the outlet. The density is defined as ρ_c; flow rate is q_c;

Outlet the density of mud flowing out of the tank is the same as the density in the tank, ρ ; flow rate is defined as q_{out}.

It is assumed that the tank level does not change with the time. The involved parameters are given in Table 5.

Description	Notation
Total flow rate of mud injected from inlets	$q_{in} = q_l + q_h + q_c$
Total flow rate of mud flowing out of outlet	q_{out}
Cross sectional area of tank	A
Liquid level in the tank	l
Density of mud in the tank	ρ
Mass of mud in the tank	m
Density of light mud	ρ_l
Density of heavy mud	ρ_h
Density of mud from inlet C	ρ_c

Table 5 Parameter's notation

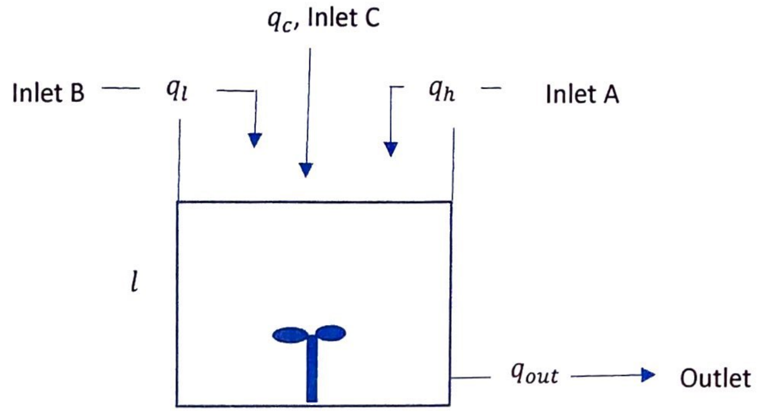


Figure 3 Sketch of tank system

Q3.2.1

Develop a dynamic model of the density of the mud in the tank.

Q3.2.2

List the important sensors used for measurements to regulate the mud density.

Q3.2.3

How to keep the mud level constant during the operations?

Q 3.2.4

The objective is to manage the density of the mud in the tank. Suppose the flow rate of light mud is selected as an input variable and the setpoint value of density of mud in the tank is given as ρ_r. The values of the parameters are given in Table 6.

Description	Notation	Values	Unit
Total flow rate of mud injected from inlets	q_{in}	1	m^3/s
Total flow rate of mud flowing out of outlet	q_{out}	1	m^3/s
Flow rate of mud injected from inlet A and inlet B	q_{ab}	0.7	m^3/s
Cross sectional area of tank	A	0.2	m^2
Liquid level in the tank	l	10	m
Mud density setpoint	ρ_r	1000	kg/m^3
Density of light mud	ρ_l	800	kg/m^3
Density of heavy mud	ρ_h	1400	kg/m^3
Density of mud from inlet C	ρ_c	1.1ρ	kg/m^3

Table 6 Parameter's values

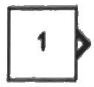
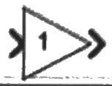
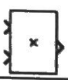
Block name	Brief description	Block
Integrator	The Integrator block outputs the value of the integral of its input signal with respect to time.	
Constant	The Constant block generates a real or complex constant value.	
Gain	The Gain block multiplies the input by a constant value (gain).	
Sum	The Sum block performs addition or subtraction on its inputs	
PID	The PID controller performs PID control function	
Saturation	Limit input signal to the upper and lower saturation values	
Product	Multiply inputs	

Table 7 Simulink blocks

The incomplete Simulink model is given in Figure 4, where the information of Simulink components used in the model are provided in Table 7. Please

(1) Make connections in Figure 4 in order to complete such model.

(2) State how the PID controller works in the system.

(3) There are some missing values of parameters in Figure 4. Please fill such values in Table 8 and describe them.

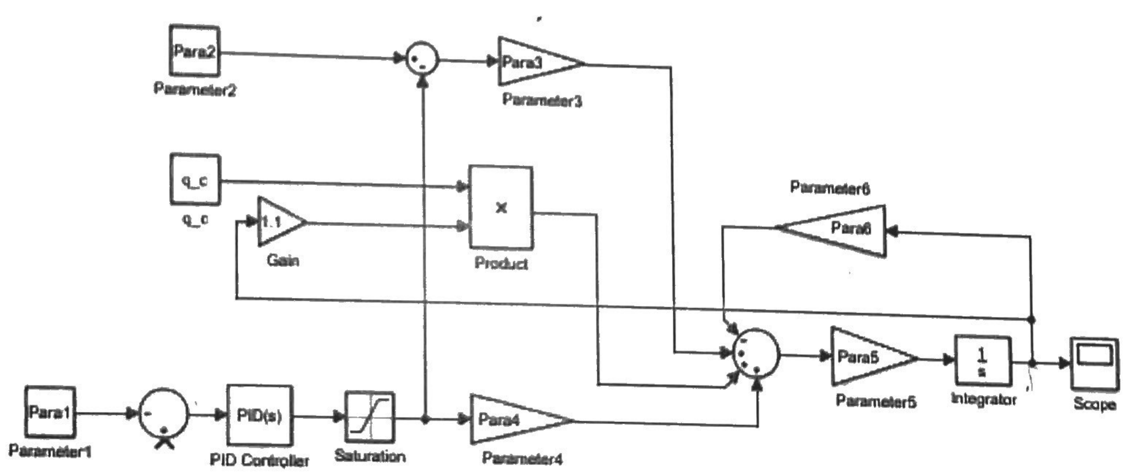


Figure 4 Simulink model

Notation	Description	Values
Parameter1		
Parameter2		
Parameter3		
Parameter4		
Parameter5		
Parameter6		

Table 8 Parameters and their values

Question 4 Drillstring

Q4.1 What is the torsional vibration of drill pipe? What are the observations of stick-slip vibrations?

Q4.2 For an undamped system

$$m\ddot{x}(t) + kx(t) = 0$$

(1) Please calculate the natural frequency of such system when m=5, k=1?

(2) When m=5 and k=0.1, does the frequency become lower or higher? Why?

Q 4.3 For forced system,

$$\ddot{x}(t) + 2\xi\omega_n\dot{x}(t) + \omega_n^2 x(t) = F(t)$$

(1) If F(t) is constant and F(t)= F_0, what is the form of its particular solution?
(2) If F(t) is $F(t)$=$F_0\sin(t)$, what is the form of its particular solution?

Q4.4 Consider the following system

$$\ddot{x}(t) + 0.4\dot{x}(t) + 4x(t) = \cos(3t)$$

where $x(0) = 1, \dot{x}(0) = 0$.

(1) Show its analytical solution.

(2) How to solve it numerically by using Euler's method?

Question 5 Drilling data

The raw dataset is given as

$$X = \{x_1,\ x_2,\ x_3,\ \dots, x_n\}.$$

Consider the following filter

$$y_k = \alpha y_{k-1} + \alpha(x_k - x_{k-1}),$$

where $0 < \alpha < 1$, x is raw data, and y is processed data. After the filter, the processed dataset becomes

$$Y = \{y_1, \quad y_2, \quad y_3, \quad \ldots, y_n\}$$

Q 5.1 What is this filter? Describe the main functions of such filter.

Q 5.2 Let

$$\alpha = \frac{\tau}{\tau + T_s}$$

where τ is the filter coefficient and T_s is the sampling rate.

(1) How does the coefficient τ affect the performance of such filter?

(2) Select the transfer function of such filter from the following options

(A) $H(s) = \frac{1}{1+\tau s}$

(B) $H(s) = \frac{\tau s}{1+\tau s}$

(C) $H(s) = \frac{\tau s}{1+\tau s+\tau s^2}$

State the reason.

Question 6 Hydraulic model

A simplified downhole wellbore MPD model is given below. Figure 5 shows the diagram of the mass flows and the pressures in the well.

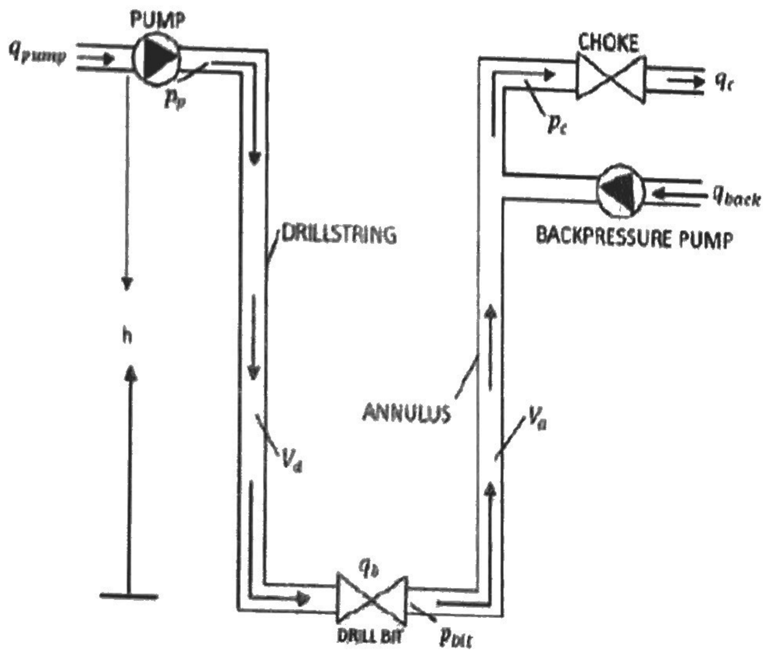


Figure 5 MPD system

The dynamic wellbore model is presented by

$$\begin{cases} \dot{P_p} = \frac{\beta_d}{V_d}(q_{pump} - q_b - \dot{V_d}) \\ \dot{P_c} = \frac{\beta_a}{V_a}(q_b - q_c + q_{back} + q_{res} - \dot{V_a}) \\ \dot{q}_b = \frac{1}{M}(P_p - P_c - \lambda_a q_b^2 - \lambda_d q_b^2 + (\rho_d - \rho_a)gh) \end{cases}$$

and bottom hole pressure can be estimated by

$$P_{bit} = P_c + M_a \dot{q}_b + \rho_a gh + \lambda_a q_b^2$$

where $M = M_a + M_d, M_a = \rho_a \int_0^{l_a} \frac{1}{A_a} dx, M_d = \rho_d \int_0^{l_d} \frac{1}{A_d} dx$. The involved drilling parameters are given in Table 9.

Para.	Description	Unit
V_a	Mud volume in annulus	m^3
V_d	Mud volume in drill string	m^3
β_a	Bulk modulus of mud in annulus	
β_d	Bulk modulus of mud in drill string	
P_c	Choke pressure	bar
P_p	Pump pressure	bar
q_b	Flow rate through the bit	m^3/s
q_c	Flow rate through the choke	m^3/s
q_{back}	Flow rate through the backpressure pump	m^3/s
q_{res}	Flow rate of influx from the reservoir	m^3/s
q_{pump}	Flow rate of the pump	m^3/s
λ_a	Friction parameter of mud in annulus	
λ_d	Friction parameter of mud in drill string	
ρ_a	Mud density in annulus	kg/m^3
ρ_d	Mud density in drill string	kg/m^3
g	Acceleration of gravity	m/s^2
h	Vertical depth of the bit	m
l_a	Length of annulus	m
l_d	Length of drill string	m
A_a	Cross sectional area of annulus	m^2
A_d	Cross sectional area of drill string	m^2
p_{bit}	Bottom hole pressure	bar

Table 6 Model parameters

Consider the choke valve model $q_c = z_c k_c \sqrt{P_c/\rho_a}$, where z_c is the valve opening, and $z_c \in [0,100]$. k_c is valve constant. In the MPD operation, the valve opening is chosen as an input variable. Assume the bottom hole pressure is the output and the reference of bottom hole pressure is given as r.

Q6.1 Draw its block diagram where the PID controller is applied to the system.

Q6.2 Suppose

$$\dot{V}_a = \dot{V}_d = 0, q_{res} = 0, \dot{P}_p = 0.$$

(1) Determine the gain (K_r) of feedforward controller with respect to the reference

$$u = K_r \dot{r}$$

and the gain (K_d) of feedforward controller with respect to the disturbances based on the above dynamic model

$$u = K_d d$$

where the disturbances (d) can be treated as q_{back} and q_{pump}.

(2) Suppose at time t, the influx comes from the reservoir ($q_{res}(t) > 0$). What does the feedforward controller with respect to the disturbances $u(t) = K_d d(t)$ change when the influx enters the well?

Question 7 Openlab Drilling Simulator

Q7.1 Back Pressure MPD:

Q7.1a The drilling mud system has several functions. One is to act as the primary barrier and prevents unintentional flow from the formation to the surface. What are the other functions of the drilling mud?

Q7.1b What is a mud weight window, and what are the main formation pressure gradients (geo-pressure margins) that need to be considered when drilling a well?

Q7.1c What is Managed Pressure Drilling (MPD) and what are the main differences with back-pressure MPD compared to conventional drilling?

Q7.1d In back-pressure MPD operations ECD in the upper part of the well is very large. Why is this?

Q7.2 Well Control:

Q7.2a A well is drilled with back-pressure MPD. During drilling a gas kick occurs. What are the immediate indications of a kick to the measurements on the rig?

Q7.2b In one of the well control methods the heavier drilling fluid (kill mud) is pumped, while at the same time, the kick is circulated out of the annulus. What is the name of this well control method?

Q7.2c What measurement at the rig is used to control bottom hole pressure during circulation when using this method?

Q7.2d What formation parameters affects the size of an influx?