# University of Stavanger-2014

**Exam:** **Advanced Drilling Technology**

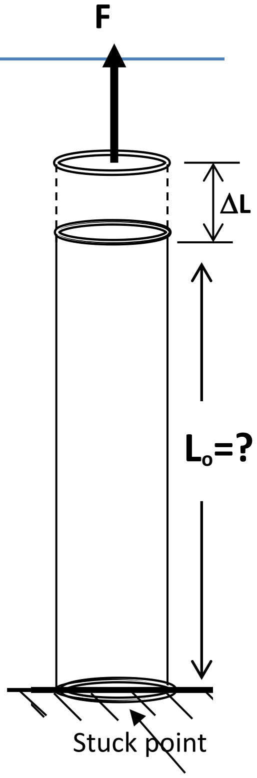
**Time:** **4 hrs**

**Calculator:** **Allowed**

The exam consists of 9 pages of exam paper and 2 pages of formula sheet

# Part I- Drilling Engineering

## Problem #1 Mechanics of materials




1. In Oil well, imagine that a driller encountered a drill string sticking problem as illustrated in Figure 1. In order to determine the point of stuck, the driller performed a pull (tensile) test on the drill string. The applied pull force ,**F**, was 600,000 N and the corresponding drill string elongation ,**ΔL**, was 2.6m. (Young's modulus, **E** = 215x10$^9$ N/m$^2$ & Cross-sectional area A =3401x10$^{-6}$ m$^2$) **(2 Points)**

**Your task** is to determine the point of stuck? In other words determine the length, $\mathbf{L_o}$, of the drill string?

Figure 1: Tensile loading on a circular, homogeneous and isotropic drill string

2. What is the engineering strain of a steel string that has been stretched from 3168.6 meter to 3171.2 meter? **(1 point)**

## Problem #2 Fluid mechanics

A fluid is flowing through 1km long and 80mm diameter pipe as shown in **Figure 2a**. The pipe surface roughness is 0.8mm and the flow friction coefficient is 0.01. The pipe carries oil density 900kg/m$^3$. The dynamic viscosity is 0.005Ns/m$^2$. Use the Moore's Chart **(Figure 2b).**

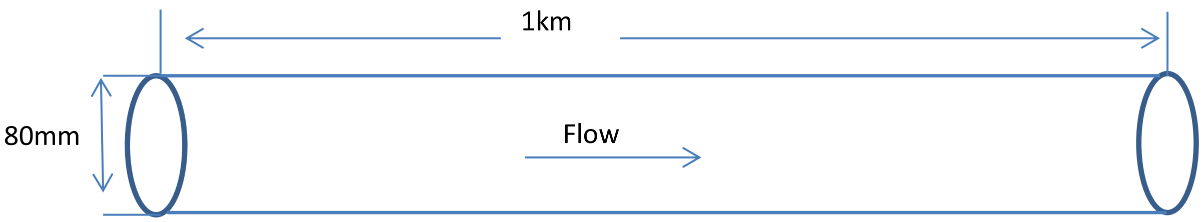



**Figure 2a**: Flow through pipe

**Your task**

1. What is the fluid flow pattern? (tell your reason) **(2 Points)**
2. Determine the velocity of fluid flow? **(1 Point)**
3. Determine the mass flow rats (kg/s)? **(1 Point)**
4. Determine pressure loss over the 1km length. **(1 Point)**

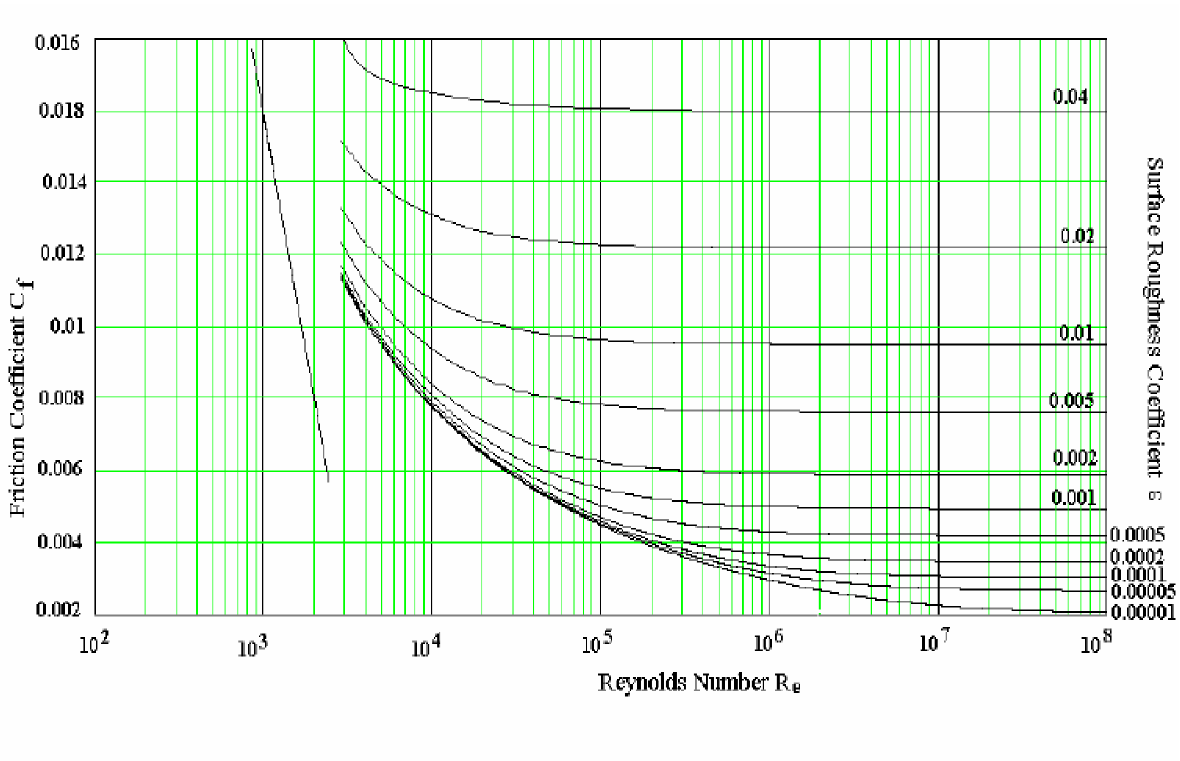



**Figure 2b**: Moore's diagram

# Problem #3 Drill string program design

A well is designed as vertical, bend and sail (or inclined) section as shows in **Figure 3**. **Table 1** below shows the design parameters used for drill string program and the result of the design is shown **Figure 4**.

**Table 1: Design parameters**

| Cross sectional area of the drill string, $m^2$ | Safety factor | Well Size, inch | Drill string OD, inch |
|---|---|---|---|
| 0,0042 | 5/4 | 9.625 | 5 |

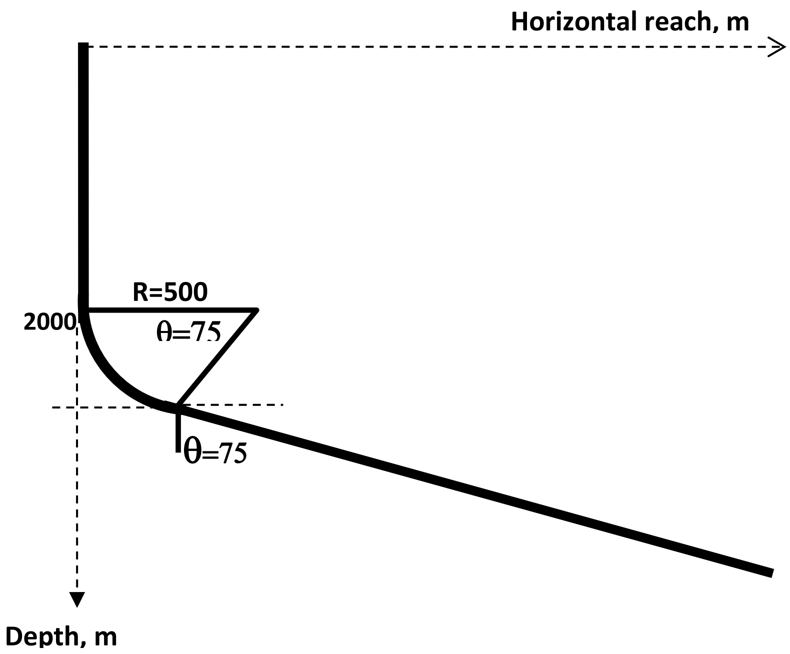



**Figure 3: Well path through which drill string program will be designed**

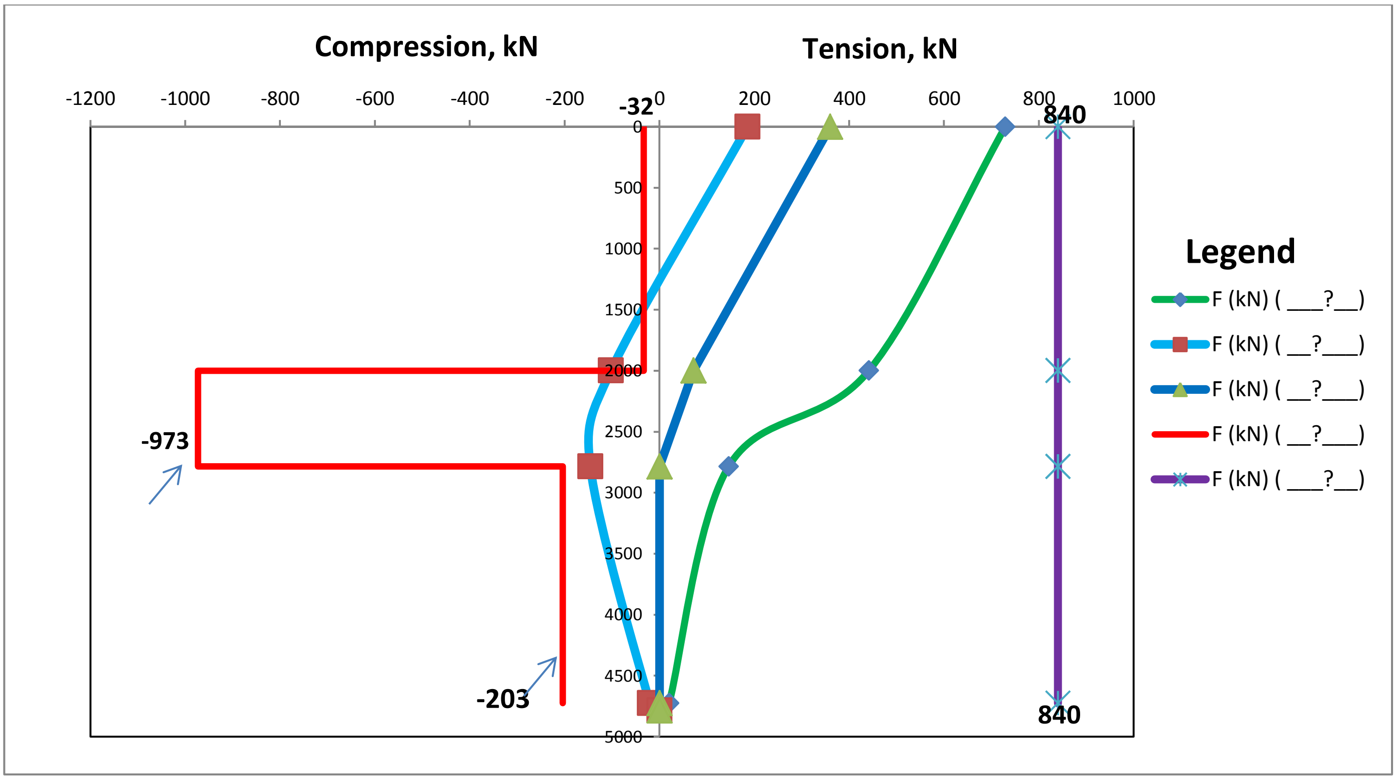



**Figure 4: Drill string program for well path shown in Figure 3**

**<u>Your task:</u>**

Using the **Figure 4** and design parameters (**Table 1),** your task is to answer the following questions

- **a)** What is the condition of the drill string**?** **(1 point)**
- **b)** Please construct the legend based on the **Figure 4** **(2.5 Points)**
- **c)** What is the yield strength of the drill string**?** **(2 points)**
- **d)** What is the product of $(w\,I\,E)$ **?** **(2 Points)**

# Problem # 4: Well-plan cutting transport Simulation

1. You are given the effect of 30ft/hr ROP on cutting transport. What is the effect of the 50ft/h and the 80ft/hr ROP on cutting transport? Please sketch your answer on the figure provided and please tell the reason why for your answer. **(2 Points)**

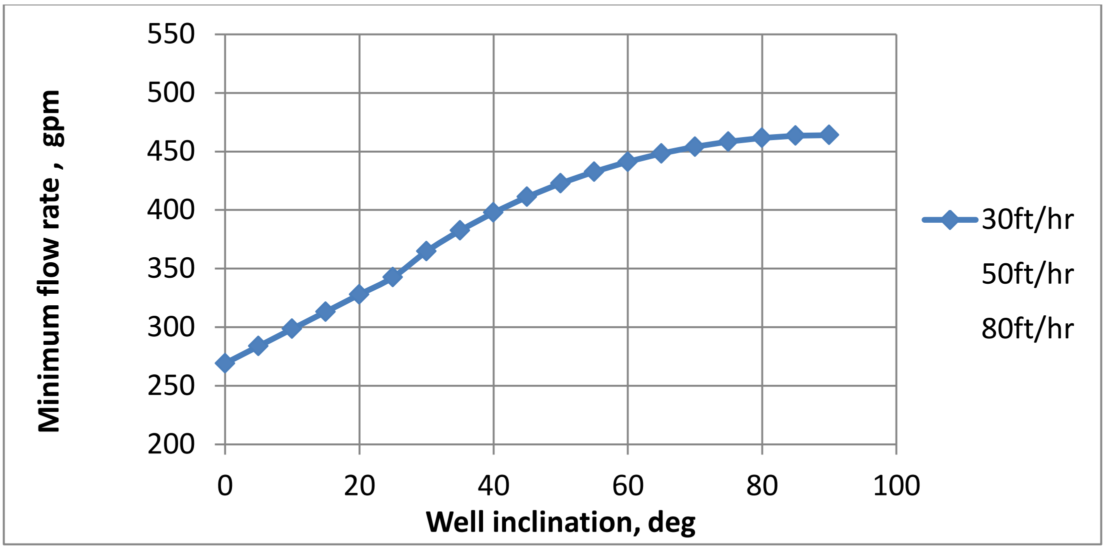



**Figure 5: Effect of ROP on cutting transport**

2 You are given the effect of 8.5ppg density of drilling fluid on cutting transport. What is the effect of 10.5ppg and 12.5ppg density of drilling fluid? Please sketch your answer on the figure provided and please tell the reason why for your answer. **(2 Points)**

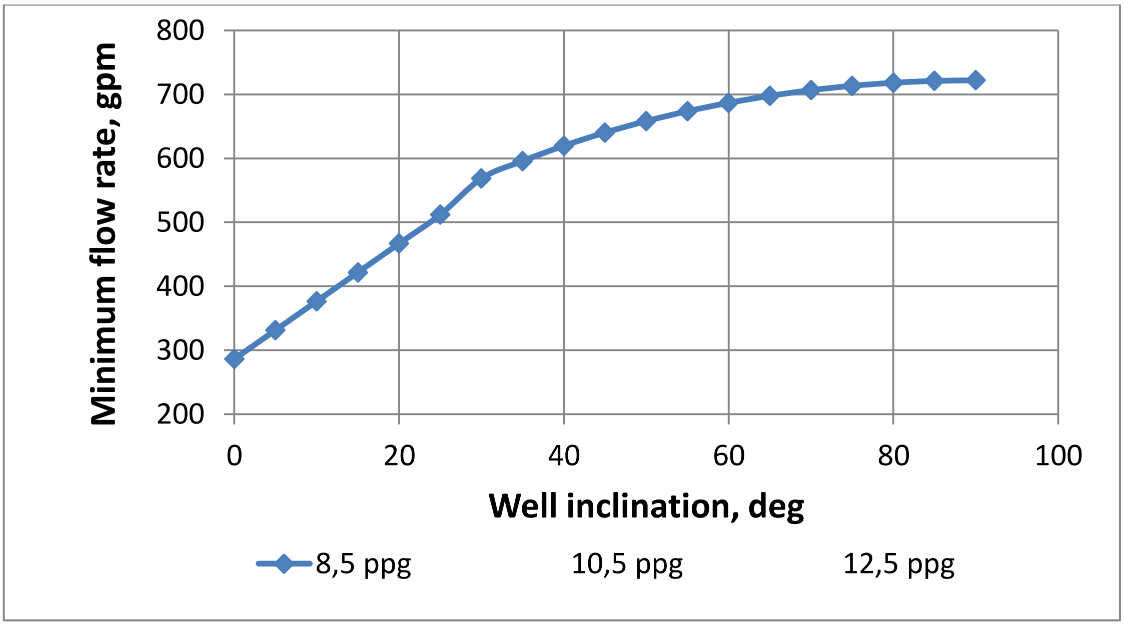



**Figure 6: Effect of density of drilling fluid on cutting transport**

# Problem #5: Well control-kill design

Drilling in a well at 4572m the driller observed several primary warning signs of kicks and proceeded with shut-in the well. After shut in was completed, the driller called the company man and started to record the shut-in drill pipe and shut-in casing pressures and pit gains after the well pressure buildups becomes stable. **Figure 7** illustrates the well, the kick and the shut-in pressures along with the length of the kick. The data for kick circulation are given in **Table 2.**

**Table 2: Pre-recorded data**

| |
|---|
| Original mud weight = 1.79 g/cc |
| Slow pump rate = 30spm at $P_{c1}$ =62 bar |
| Drill pipe volume = 300 bbl |
| Annulus volume =700 bbl |
| Pump output = 0,2 bbl/strokes |
| True vertical depth = 4572m |
| Pit gain = 40 bbl |
| Height of gas kick = 122m |

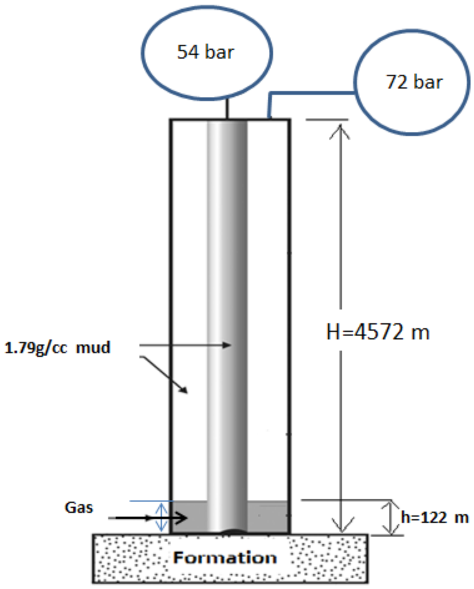



Figure 7

The company decided to kill the well by the wait and weight method. **Your task!**

1. Please write a shut in procedure (at least mention four points) **(2Points)**
2. What is the initial circulation pressure? **(1Point)**
3. What is the final circulation pressure? **(2Points)**
4. What is the formation pressure? **(2Points)**
5. What is the density of kick? **(2Points)**
6. Please draw the draw the pressure vs stroke pumped for the for the drill string and annulus **(2P)**
7. Please calculate the pump pressure when the strokes pumped was 100 strokes. **(2 Points)**

## Problem #6: Well control-Kill interpretation

Please answer the following based on **Figure 8**

1. For what kind of kill method the following curve represents for? **1P**
2. What happen during kick killing process when the pressure vs stroke is from **A-B?** **1P**
3. What happen during kick killing process when the pressure vs stroke is from **B-C?** **1P**
4. What happen during kick killing process when the pressure vs stroke is from **C-D?** **1P**

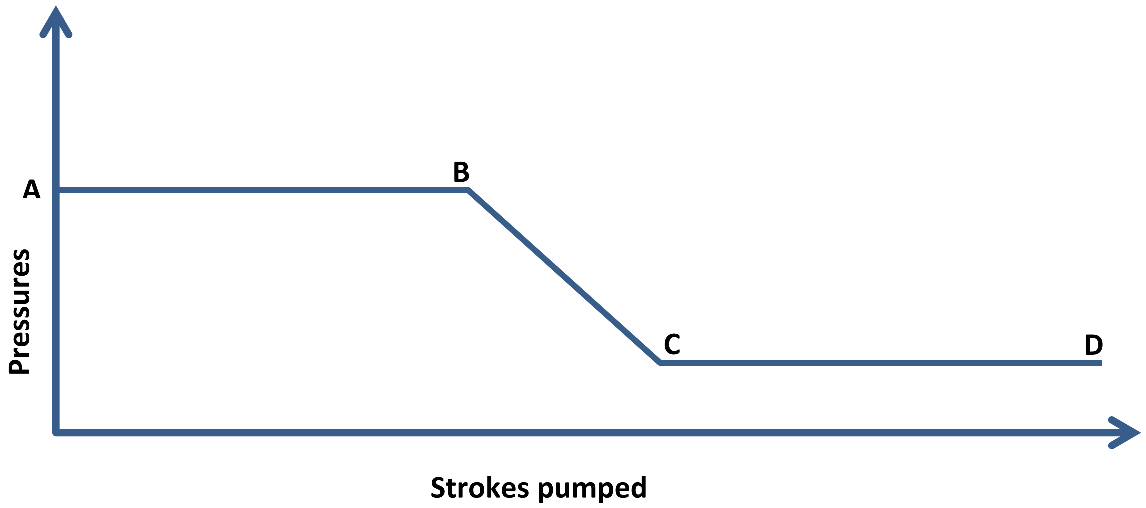



**Figure 8:**

## Problem #7 Innovative drilling method

1. What is the difference between conventional and MPD drilling methods? **1 Point**
2. Please mention three surface equipment and one downhole equipment of MPD. **2 Points**
3. How can we detect kick occurrences? **2 Points**

# Part II- Drilling automation

## Exercise 1: Signal processing

The pump pressure signal in a drilling control system is processed using two low-pass filters with different tau- value. A zoomed view of the original signal and the two filtered signals are shown in Figure 1.

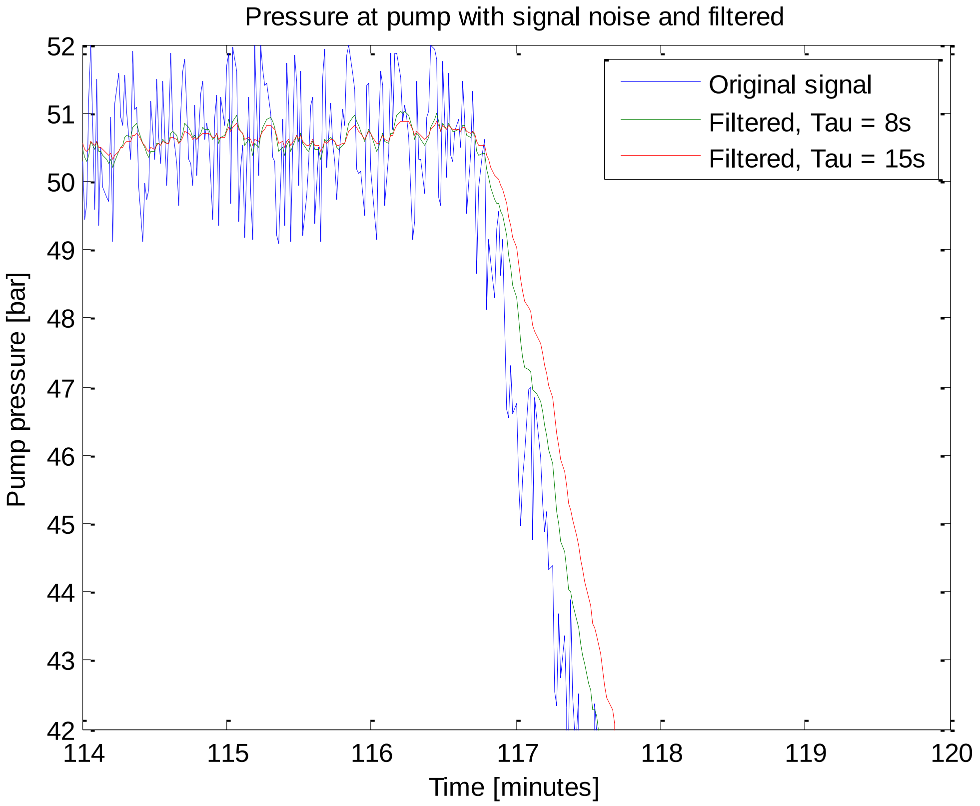



**Figure 1 Zoomed view of pump pressures, original pressure signal values, and filtered using different tau (τ) values.**

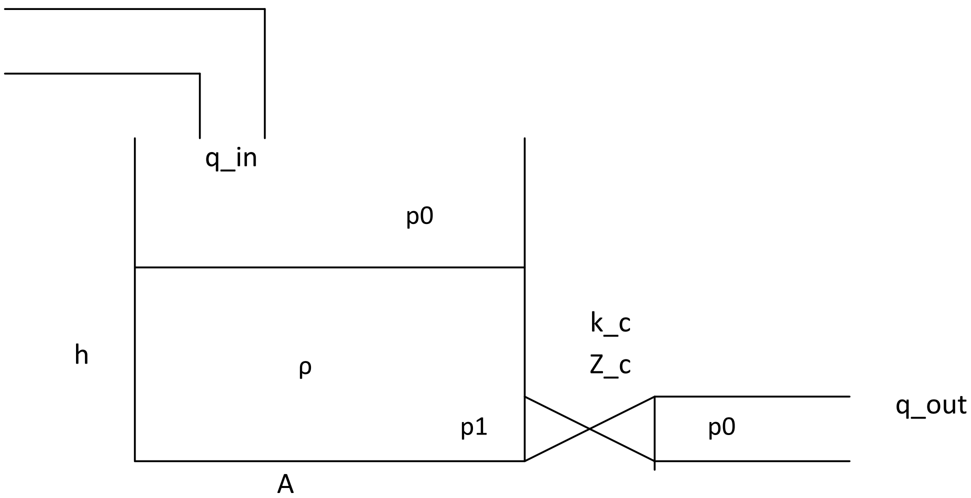
A) At the time 114 to 116 the pressure signal is in relatively steady-state condition, and the difference between the two low-pass filters are minimal. Explain why the difference between the two low-pass filters are more visible in the transient phase from time 117 to 118.

## Exercise 2: Modelling

A schematic view of a drilling fluid tank is given in Figur , with the following notation:

q_in : drilling fluid flowing into the tank,
q_out : drilling fluid flowing out of the tank,
A : area of the tank
h : liquid level height

p0 :  atmospheric pressure
p1 : pressure in front of the valve
ρ :  density of the fluid,
k_c  : valve constant,
z_c  : valve opening.




**Figur 2 Drilling tank system**

The following relations are given:

Mass balance for a tank with constant density:

$$\rho \frac{dV}{dt} = \rho(q_{in} - q_{out})$$

The valve equation:

$$q_{out} = z_c k_c \sqrt{\frac{\Delta p}{\rho}}$$

Hydrostatic pressure:

$$p_1 = \rho g h + p_0$$

Euler's method:

$$x(t_{k+1}) = x(t_k) + \dot{x} dt$$

**A)** Develop a dynamic model of the tank level.
**B)** Assume the tank level at time step, t_0, is known. Express the tank level at time step t_1 using Euler's method-

## Exercise 3: Control theory

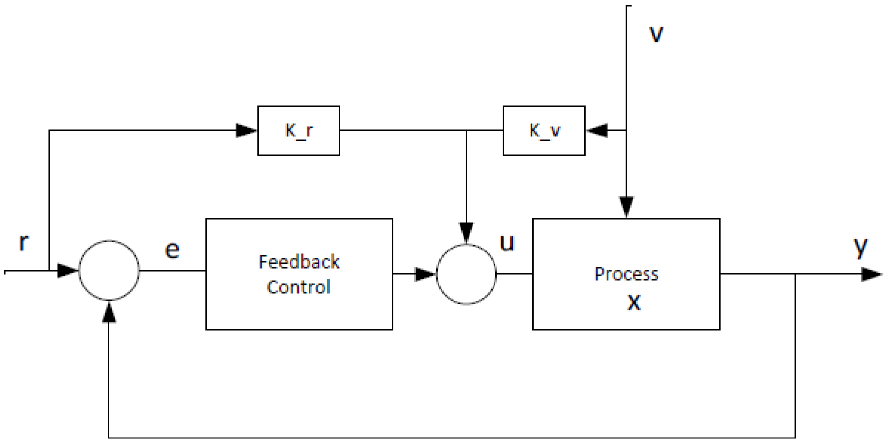



**Figure 3 Control theory notation**

The diagram in Figure  presents a control system implementation using the following main terms:

- feed-back control
- feed-forward control from the reference
- feed-back control from the disturbance

This can also be explained using the following equation:

Linear control algorithm

$$u = u_0 + K_p e + \frac{K_p}{T_i}\int_0^t e d\tau + K_p T_d \dot{e} + K_r \dot{r} + K_v v$$

**A)** Describe every element of the linear control algorithm in the above equation.
**B)** How is the values K_r and K_v typically found?

# Formula sheet

$$\varepsilon = \frac{l - l_o}{l_o} \qquad \Delta L = \frac{FL_o}{EA} \qquad \sigma = \frac{F}{A} \qquad SF = \frac{\sigma_y}{\sigma_{\max}}$$

## Buckling

| Section | Sinusoidal | Helical |
|---|---|---|
| Vertical | Wu et al. (1992): $\mathrm{F_{sin}} = 2.55(\mathrm{EIw^2})^{1/3}$ | Wu et al. (1993): $\mathrm{F_{hel}} = 5.55(\mathrm{EIw^2})^{1/3}$ |
| Curved | Mitchell (1999): $\mathrm{F_{sin}} = \frac{2\mathrm{EIk}}{\mathrm{r}}\left[1 + \sqrt{\frac{\mathrm{wsin\theta r}}{\mathrm{EIk^2}}}\right]$<br>• $\mathrm{k} = {}^{1}/_{\mathrm{R}}$ (build or drop)<br>• $\mathrm{r} = \frac{1}{2}\left(\mathrm{ID_{well/casing}} - \mathrm{OD_{tubing}}\right)$<br>r = Radial clearance | Mitchell (1999): $\mathrm{F_{hel}} = 2.83\mathrm{F_{sin}}$ |
| Inclined | Dawsons and Paslay (1984): $\mathrm{F_{sin}} = 2\left(\frac{EIwsin\theta}{r}\right)^{0.5}$<br>• r = Radial clearance<br>θ= incllination | Chen et al. (1989): $\mathrm{F_{hel}} = \sqrt{2}F_{dowson\ pasley}$ |

**Table: Buckling in the vertical, bend and inclined sections**

**Cutting transport**

| | | |
|---|---|---|
| **Cutting transport** | Settling velocity (Stocke's law)<br>$v_s \approx \frac{gd_c^2(\rho_c - \rho_f)}{18\mu_{eff}}$ | Transport velocity<br>$V_T = V_Q - Vs$<br>$V_Q = Q/A$ |

The surface roughness coefficient ➔ ε = k/d

k = surface roughness and d = diameter of the pipe

**Reynolds number**

$$R_e = \frac{\rho . V . D}{\mu}$$

**Hydrostatic pressure and pressure loss**

P [bar] = 0.098*density [sg]*TVD[m]  (the density is in sg, and TVD is in, m )

$$\Delta p = \frac{2C_f \rho V^2}{D} L$$

$$\frac{1}{\sqrt{C_f}} = -3.6 \log_{10} \left\{ \frac{6.9}{R_e} + \left( \frac{\varepsilon}{3.71} \right)^{1.11} \right\}$$

# Well control

$$FCP = P_{c1} \frac{KMW}{OMW}$$

$$KMW[sg] = OMW[sg] + \frac{SIDP[bar]}{0.098 TVD[m]}$$

$$KMW[ppg] = OMW[ppg] + \frac{SIDP[psi]}{0.052 TVD[ft]}$$

$$Drillpipe.strokes = \frac{Drillpipe.Volume(bbl)}{pump.output(bbl / stroke)}$$

$$Annulus.strokes = \frac{Annulus.Volume(bbl)}{pump.output(bbl / stroke)}$$

$$ICP = SIDP + P_{c1}$$

**Conversion**

1 MPa = 10 bar

100 kPa = 1bar

1 bar = 14.5 psi

1 sg = 8.33 ppg

1 ft = 0.3048m

1in = 0.0254m