NTNU

Department of energy and process engineering

Examination paper for TEP4200, Mechanical Design, Operation and Maintenance of Hydraulic Machinery

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Examination time (from-to): 09:00 – 13:00

Permitted examination support material: D

No written and handwritten examination support materials are permitted. A simple calculator is permitted.

Other information:

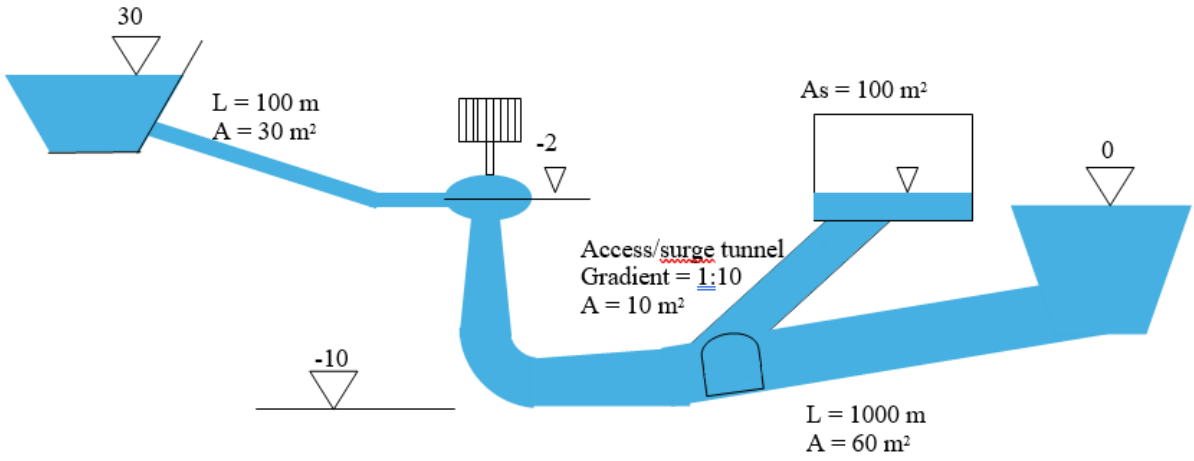
- You have to fill out and deliver all questions pages, 2 to 5, as your solution. No written notes should be delivered.
- For Multiple choice questions there can be more than one marked check box for each question. Correct answers are rewarded with one point (1p.) while incorrect answers give zero point (0p.).
- True or false are rewarded with one point (1p.) for correct answer, while incorrect answers give zero point (0p.).
- Choose the options closest to the calculated solutions.

Language: English

Number of pages (front page excluded):

Number of pages enclosed:

Problem 1. System dynamics (max. 12 points)



Frequency and period of U-tube oscillation	$\omega = \sqrt{\frac{g}{A_{shaft} \cdot \Sigma \frac{L}{A}}} \qquad T = \frac{2 \cdot \pi}{\omega}$
Penstock time constant and retardation/acceleration pressure	$T_w = \frac{Q}{g \cdot H} \cdot \Sigma \left({}^{L}/_{A} \right)$
Up- or down-surge in the surge shaft	$\Delta z = \Delta Q \cdot \sqrt{\frac{\Sigma (L/A)}{g \cdot A_{shaft}}}$
Thoma Cross section	$A_{Thoma} = 0{,}0083 \frac{M^2 A_{tunnel}^{\,5/3}}{H_e}$

1	A power plant is under construction with a lay-out as shown in the Figure above. The flow rate Q = 60 m^3/s, and gross head of 30m. The project has access tunnel, which will later be used as surge shaft during operation phase. The overall head loss in the conduit system has been estimated to be 0,0015Q^2	Check box
1A.	Calculate the effective head of the conduit system. **(**Single-choice question)	
i	Effective Head: H_e = 32 m	
ii	Effective Head: H_e = 28 m	
iii	Effective Head: H_e = 35,4 m	
iv	Effective Head: H_e = 24,6 m	X

$Head\ loss = 0{,}0015Q^2 \qquad H_e = 30 - 0{,}0015 * 60^2 = 24{,}6\ m$

1B.	If the Length-cross section ratio is 0,5 for the section between the turbine and entrance at the access tunnel, determine the penstock time constant for the project. **(**Single-choice question)	
i	T_W = 3,0 s	
ii	T_W = 0,97 s	
iii	T_W = 3,5 s	X
iv	T_W = 0,85 s	

$$T_w = \frac{Q}{gH} \cdot \sum \frac{L}{A} = \frac{1}{g * 24{,}6} \cdot \sum \left(\frac{100}{30} + 0{,}5 + \frac{100{,}5}{10}\right) = 3{,}5\ s$$

1C. Considering that the acceleration time constant, $T_a = 7s$, which of the following is a correct statement. (Single-choice question)		
i	Governer stability is sufficient because $T_a/T_w > 6$	
ii	Governer stability is insufficient because $T_a/T_w > 6$	
iii	Governer stability is sufficient because $T_a/T_w < 6$	
iv	Governer stability is insufficient because $T_a/T_w < 6$	X

$\frac{T_a}{T_w} = \frac{7}{3{,}5} = 2 < 6; Insufficient\ governer\ stability$

1D. If Manning number for the tunnels is 38, which of the following regarding the stability of U-tube oscillations in the tailrace is true. (Single-choice question)		
i	U tube oscillations are stable because $A_s > A_{Thoma}$	
ii	U tube oscillations are unstable because $A_s > A_{Thoma}$	
iii	U tube oscillations are stable because $A_s < A_{Thoma}$	X
iv	U tube oscillations are stable because $A_s < A_{Thoma}$	

$$A_{Thoma} = 0{,}0083 \frac{M^2 A_{tunnel}^{5/3}}{H_e} = 0{,}0083 \frac{38^2 60^{5/3}}{24{,}6} = 448\ m^2$$

$A_s < A_{Thoma}$: Unstable U-tube oscillations

1E. Maximum surge in the tail water surge shaft, neglecting the losses, is: (Single-choice question)		
i	$\Delta z = 9{,}9$ m	X
ii	$\Delta z = 10{,}5$ m	
iii	$\Delta z = 8{,}7$ m	
iv	$\Delta z = 6{,}2$ m	

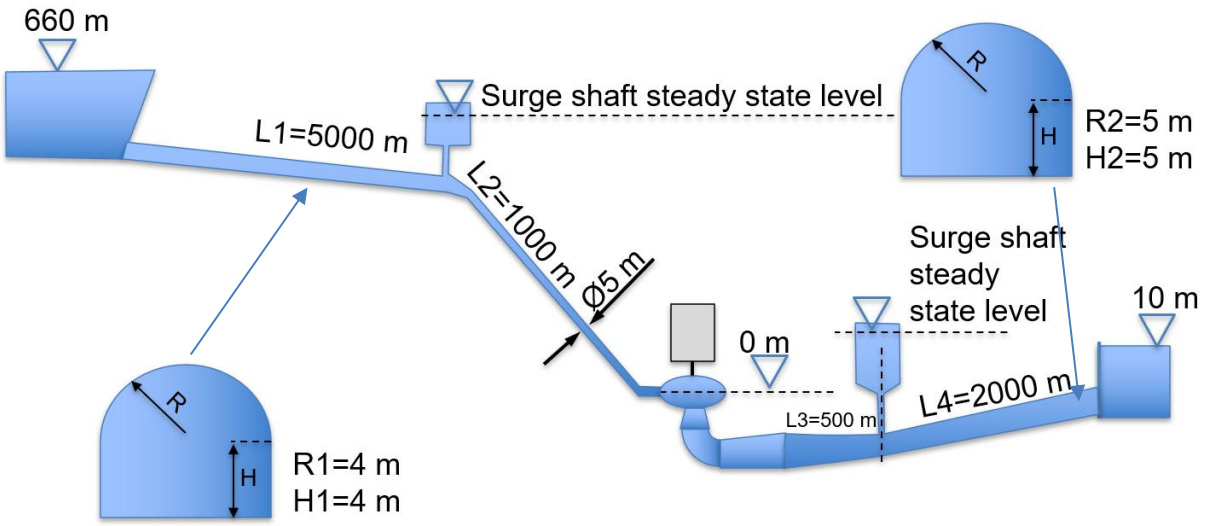
$$\Delta z = \Delta Q \cdot \sqrt{\frac{\Sigma(L/A)}{g \cdot A_{shaft}}} = 60 * \sqrt{\frac{\left(101{,}5/10 + 1000/60\right)}{9{,}81 * 100}} = 9{,}9\ m$$

1F. Calculate the Time period of the U-tube oscillations of the maximum tail water surge		
i	T = 103,7 s	X
ii	T = 90,8 s	
iii	T = 32,8 s	
iv	T = 3,5 s	

$$\omega = \sqrt{\frac{g}{A_{shaft} \cdot L/A}} = \sqrt{\frac{9{,}81}{100 \cdot \left(\frac{101{,}5}{10} + \frac{1000}{60}\right)}} = 0{,}061\ rad/s$$

$$T = \frac{2 \cdot \pi}{\omega} = 103{,}7\ s$$

Problem 2. Head Loss (max. 10 points)



$$h_f = \frac{L}{M^2} \cdot \frac{c^2}{{R_h}^{4/3}} \qquad R_h = \frac{A}{P} \qquad h_f = \lambda \cdot \frac{L}{D} \cdot \frac{c^2}{2 \cdot g}$$

Given data:

	Symbol		Unit
Gravity constant	g	9,81	m/s^2
Mannings constant	M	34	$m^{1/3}/s$
Friction factor penstock	λ	0,012	-
Turbine efficiency	η_t	94	%
Generator efficiency	η_G	98	%
Transformer efficiency	η_T	99	%
Penstock material roughness	ε	0,4	mm
Diameter of the penstock	D	4,0	m
Flow rate	Q	150	m^3/s

Note: Ignore the minor losses

2	Calculate the following for the hydropower plant with tunnel and penstock as shown in the figure above: (Multiple-choice question)	Check box
2a	Head loss in the headrace tunnel: H_f = 9,9 m	
2b	Head loss in the headrace tunnel: H_f = 11,8 m	X
2c	Head loss in the headrace tunnel: H_f = 4,7 m	
2d	The steady state level in upper surge shaft = 638,2 m	
2e	The steady state level in upper surge shaft = 660,0 m	
2f	The steady state level in upper surge shaft = 648,2 m	X
2g	Generator power output: P_T = 884,4 MW	
2h	Generator power output: P_T = 870,4 MW	
2i	Generator power output: P_T = 852,9 MW	X
2j	The steady state level in the lower surge shaft = 8,6 m	

2k	The steady state level in the lower surge shaft = 11,8 m	
2l	The steady state level in the lower surge shaft = 11,4 m	X
2m	The net head of the turbine; H_n = 629,2 m	X
2n	The net head of the turbine; H_n = 639,2 m	
2o	The net head of the turbine; H_n = 631,0 m	

Problem 3. Mass and pressure oscillations (max. 10 points)

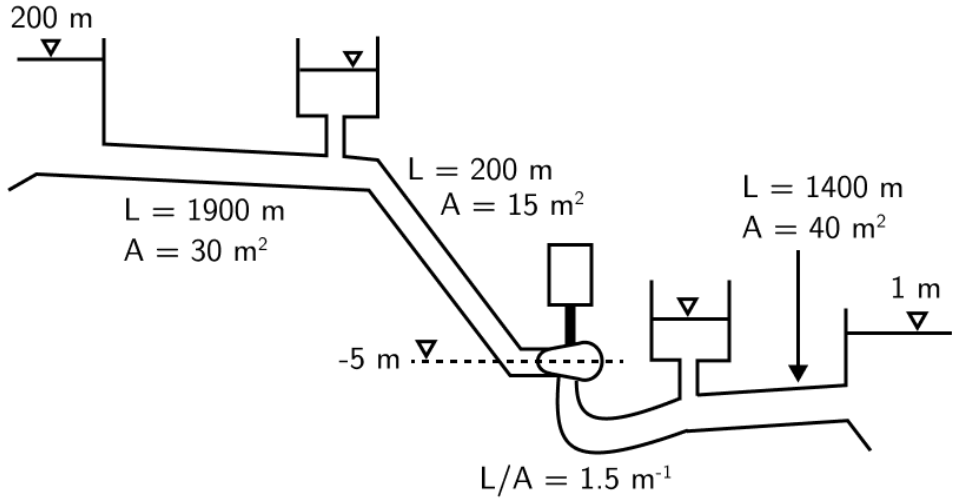


Figure 1 - Planned layout of a hydropower plant

Frequency and period of U-tube oscillation	$\omega = \sqrt{\frac{g}{A_{shaft} \cdot {}^{L}/_{A}}} \qquad T = \frac{2 \cdot \pi}{\omega}$
Penstock time constant and retardation/acceleration pressure	$T_w = \frac{Q}{g \cdot H} \cdot \sum \frac{L}{A} \qquad \Delta H = \frac{1}{g} \cdot \sum \frac{L}{A} \cdot \frac{\Delta Q}{T_C}$
Water hammer and reflection time	$\Delta H = \Delta v \cdot \frac{a}{g} \cdot \frac{T_R}{T_C} \qquad T_R = \frac{2L}{a}$
Up- or down-surge in the surge shaft	$\Delta z = \Delta Q \cdot \sqrt{\frac{\Sigma(L/A)}{g \cdot A_{shaft}}}$
Thoma criterion	$A_{Th} \approx 0.0085 \cdot \frac{M^2 \cdot A_T^{5/3}}{H_0}$

3	A power plant is under construction with a lay-out as shown in Figure 1 above. The flow rate Q = 35 m^3/s and the Mannings number is 34.	Check box
3A. What is the minimum area of the upper surge shaft that will ensure stable U-tube oscillations? (Single-choice question)		
The minimum upper surge shaft area is: A_{Min} = 14.3 m^2		X
The minimum upper surge shaft area is: A_{Min} = 55.8 m^2		
The minimum upper surge shaft area is: A_{Min} = 42.9 m^2		
The minimum upper surge shaft area is: A_{Min} = 22.4 m^2		

$$A_{min} = A_{Th} \approx 0.0085 \cdot \frac{M^2 \cdot A_T^{5/3}}{H_0} = 0.0085 \cdot \frac{34^2 \cdot 30^{5/3}}{200 - 1} = 14.3\ m^2$$

3B. Calculate the area of the upper surge shaft if Δz < 12 m. Neglect the head loss. (Single-choice question)	
The area of the upper surge shaft is: A_{Shaft} = 46 m^2	
The area of the upper surge shaft is: A_{Shaft} = 49 m^2	
The area of the upper surge shaft is: A_{Shaft} = 55 m^2	X
The area of the upper surge shaft is: A_{Shaft} = 34 m^2	

$$\Delta z = \Delta Q \cdot \sqrt{\frac{\Sigma(L/A)}{g \cdot A_{shaft}}} \qquad A_{shaft} = \Delta Q^2 \cdot \frac{\Sigma(L/A)}{g \cdot \Delta z^2} = 35^2 \cdot \frac{\frac{1900}{30}}{9.81 \cdot 12^2} = 55\ m^2$$

3C. Assume no surge shaft is installed upstream. Calculate the change of pressure at the turbine inlet according to rigid theory when the turbine closes in T_C = 10 s. (Single-choice question)	
The change of pressure at the turbine inlet is: ΔH = 24.4 m	
The change of pressure at the turbine inlet is: ΔH = 44.2 m	
The change of pressure at the turbine inlet is: ΔH = 39.4 m	
The change of pressure at the turbine inlet is: ΔH = 28.3 m	X

$$\Delta H = \frac{1}{g} \cdot \sum \frac{L}{A} \cdot \frac{\Delta Q}{T_C} = \frac{1}{9.81} \cdot \left(\frac{1900}{30} + \frac{200}{12.5}\right) \cdot \frac{35}{10} = 28.3\ m$$

3D. Include the upstream surge shaft. Calculate the water hammer at the turbine inlet when the turbine closes in T_C = 10 seconds and a = 1200 m/s. (Single-choice question)	
The water hammer at the turbine inlet is: ΔH = 24.4 m	
The water hammer at the turbine inlet is: ΔH = 6.3 m	
The water hammer at the turbine inlet is: ΔH = 9.4 m	X
The water hammer at the turbine inlet is: ΔH = 13.5 m	

$$T_R = \frac{2L}{a} = \frac{2 \cdot 200}{1200} = 0.33\ s \qquad \Delta H = \Delta v \cdot \frac{a}{g} \cdot \frac{T_R}{T_C} = \frac{35}{15} \cdot \frac{1200}{9.81} \cdot \frac{0.33}{10} = 9.4\ m$$

3E. The surge shaft downstream of the turbine has an area of 120 m^2. Calculate the period of the down surge at shut down from a flow rate of Q = 35 m^3/s. (Single-choice question)	
The surge period is: T = 120 s	
The surge period is: T = 130 s	X
The surge period is: T = 140 s	
The surge period is: T = 150 s	

$$\omega = \sqrt{\frac{g}{A_{shaft} \cdot L/A}} = \sqrt{\frac{9.81}{120 \cdot (1400/40)}} = 0.0483\ s^{-1} \qquad T = \frac{2 \cdot \pi}{\omega} = \frac{2 \cdot \pi}{0.0483} = 130\ s$$

Problem 4. Governing and stability (max. 12 points)

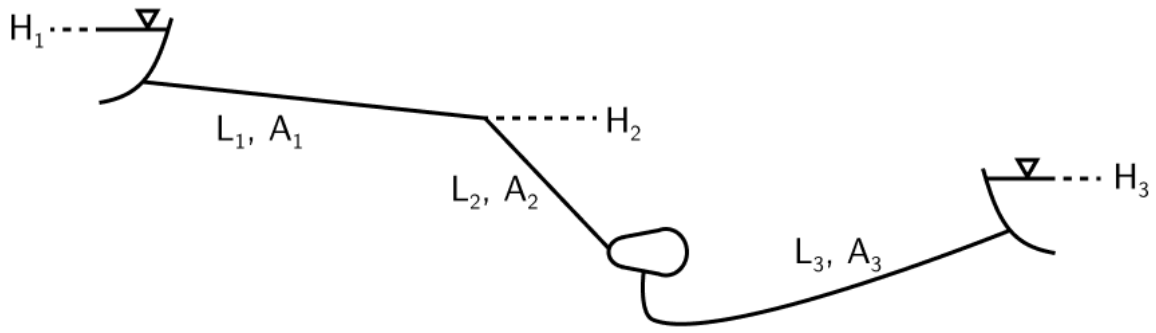


Figure 2 - Planned layout of a hydropower plant without a surge shaft

H_1	400 m	L_1	3500 m	A_1	50 m^2
H_2	250 m	L_2	300 m	A_2	20 m^2
H_3	10 m	L_3	1000 m	A_3	50 m^2

Table 1 - Main system dimensions

Penstock time constant and acceleration time constant	$T_w = \frac{Q}{g \cdot H} \cdot \sum \frac{L}{A} \qquad T_a = J \cdot \frac{\omega_0^2}{P_{max}}$
PID controller	$u = u_0 + K_p \cdot e + \frac{K_p}{T_i} \cdot \int_0^t e \, d\tau + K_p \cdot T_d \cdot \frac{de}{dt}$
Open-loop transfer function of a simple hydropower system with a PI-controller	$A(s) = \frac{1}{b_t \cdot T_d \cdot T_a} \cdot \frac{(1 + T_d \cdot s) \cdot (1 - T_w \cdot s)}{s^2 \cdot (1 + 0.5 \cdot T_w \cdot s)}$
Proportionality constant and integral constant	$b_t = 2.6 \cdot \frac{T_w}{T_a} \qquad T_d = 6 \cdot T_w$

4	A power plant is under construction with a lay-out as shown in Figure 2 and Table 1 above. The design flow rate is Q = 47 m^3/s.	Check box
4A. What is the penstock time constant of the proposed hydropower system? (Single-choice question)		
The penstock time constant is: T_w = 0.73 s		
The penstock time constant is: T_w = 0.95 s		
The penstock time constant is: T_w = 1.07 s		
The penstock time constant is: T_w = 1.29 s		X

$$T_w = \frac{Q}{g \cdot H} \cdot \sum \frac{L}{A} = \frac{47}{9.81 \cdot (400 - 10)} \cdot \left(\frac{3500}{50} + \frac{300}{20} + \frac{1000}{50}\right) = 1.29\ s$$

4B. True-False The acceleration time constant T_a = 6 s. Evaluate the following claims: (True or False question)			
i	The proposed layout ensures sufficient governing stability.		False
ii	An upstream surge shaft can decrease the inertia of the water masses in the system and improve stability.	True	

iii	Longer tunnels will decrease the inertia of the water masses in the system and improve stability.		False
iv	A larger turbine will increase inertia of the rotating masses in the system and improve stability.	True	

$\frac{T_a}{T_w} > 6$ $\frac{6}{1.29} = 4.56 < 6$ Not sufficient.

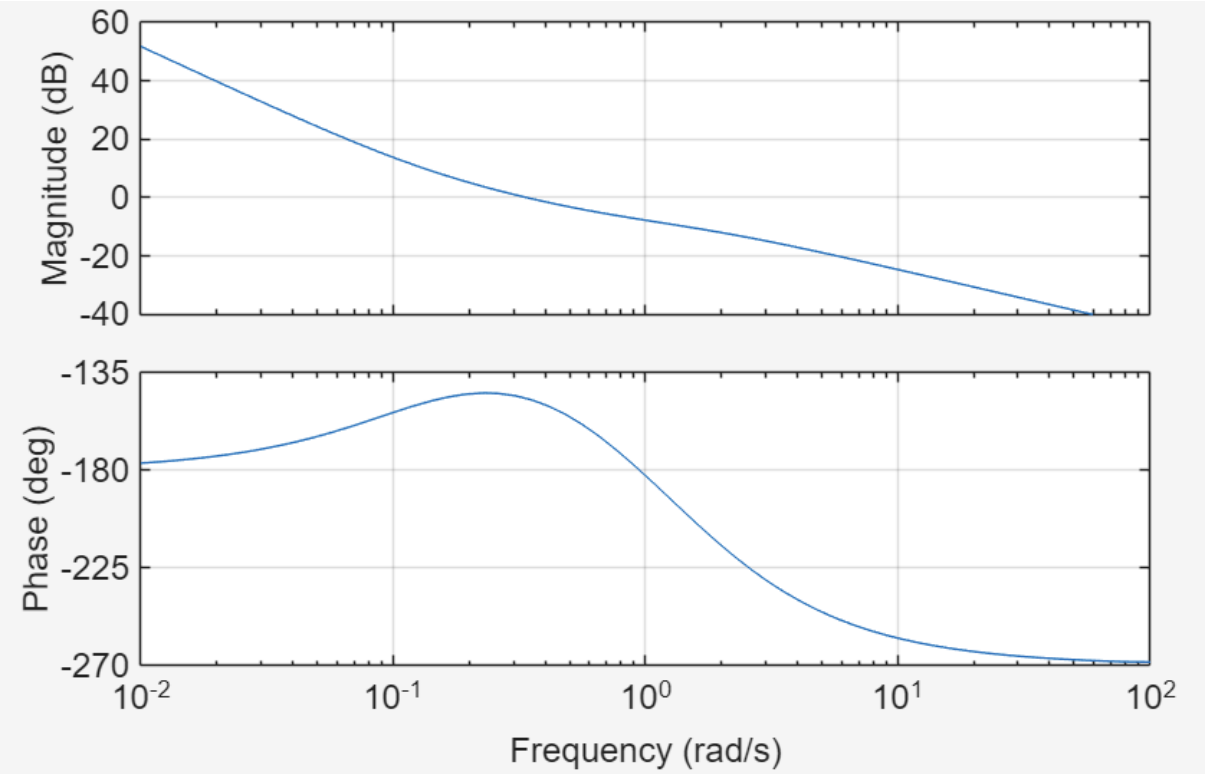


Figure 3 - APF diagram of the proposed system

4C. What is the amplification margin of the system? (Single-choice question)	
The amplification margin is: $\Delta\kappa \approx 7$ dB	X
The amplification margin is: $\Delta\kappa \approx 19$ dB	
The amplification margin is: $\Delta\kappa \approx 26$ dB	
The amplification margin is: $\Delta\kappa \approx 33$ dB	

4D. What is the phase margin of the system? (Single-choice question)	
The phase margin is: $\Delta\psi \approx 7$ deg	
The phase margin is: $\Delta\psi \approx 33$ deg	X
The phase margin is: $\Delta\psi \approx 45$ deg	
The phase margin is: $\Delta\psi \approx 57$ deg	

4E. True-False Evaluate the following claims: (True or False question)			
i	The turbine rotational speed will decrease if the hydraulic power is higher than the electric power to the grid.		False
ii	The deviation limit in the Nordic power grid is 0.1 Hz.	True	
iii	The main types of frequency control are primary, secondary, and tertiary.	True	

iv	Hydropower governing is always done with PI-controllers.		False

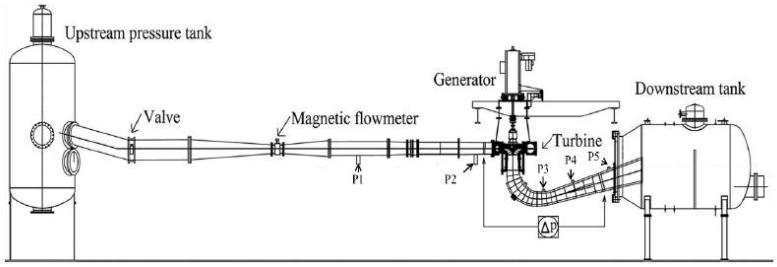
4F. Which of the following is **not** a method to improve governing stability? (Single-choice question)	
Changing the gain of the gain of the controller to adjust the responsiveness of the governing system.	
Changing the integral or derivative time constants to modify the dynamic response of the governor.	
Changing the capacity of the transformer to allow higher power transfer to the grid.	X
Changing the system layout before construction to lower the inertia of the water masses.	

Problem 5. Hydro Turbines (max. 10 points)

5	**State whether the following statements are true or false.** (True or False statements)	True	False
5a	Reversible pump turbines require higher submergence compared to a Francis turbine.	X	
5b	Scale effects cause relatively higher friction losses in model turbines than in full scale prototypes.	X	
5c	At best efficiency operation of a Francis turbine, the rotational component of the relative velocity, $w_{\theta 2}$ at the outlet to the runner is zero.		X
5d	At Francis turbine part load operation, the rotational component of the absolute velocity, $c_{\theta 2}$ at the outlet of the runner is in the opposite direction of the peripheral velocity of the runner, u_2		X
5e	At part load operation of a Pelton turbine, the rotational component of the absolute velocity at the outlet to the runner is in the same direction of the peripheral velocity of the runner, u_2.	X	
5f	The Euler turbine equation directly relates the change in angular momentum to energy transfer in turbomachinery.	X	
5g	Fish friendly turbines are the only turbines that can be installed in any new hydropower project in Norway.		X
5h	In a Pelton turbine, the speed of rotation also affects the flow rate through the turbine.		X
5i	In a Francis turbine, the speed of rotation also affects the flow rate through the turbine.	X	
5j	Pelton turbines are usually chosen for projects with low specific speed	X	

Problem 6. Francis turbine model tests (max. 12 points)

Model of a Francis turbine is tested at the lab and the measurement along with other geometrical parameters of the rig are given below.



Given data:

	Symbol		Unit
Inlet pressure on the model turbine	p_{in}	235	kPa
Differential pressure across the model turbine	Δp	160	kPa
Atmospheric pressure	p_{atm}	93	kPa
Flow rate on the model turbine	Q_M	245	l/s
Gravity constant	g	9,8	m/s^2
Density of water	rho	1000	kg/m^3
Pipe diameter at the inlet of the turbine where high pressure side of Δp is tapped	D_{inlet}	349	Mm
Area at the outlet of the turbine where low pressure side of Δp is tapped	A_{outlet}	0,236	m^2
Level at the inlet	Z_{in}	2	m
Level at the outlet	Z_{out}	1	m
Model Turbine Torque	M_T	900	Nm
Model Turbine Speed	n_M	350	rpm
Prototype Turbine Speed	n_P	375	rpm
Generator efficiency	h_G	0,99	-
Model Turbine runner outlet diameter	D_M	0,35	m
Prototype Turbine runner outlet diameter	D_P	1,78	m
Number of runner blades	Z_{runner}	30	-
Number of guide vanes	$Z_{guide\ vanes}$	28	-

6	**(**Multiple-choice question)		Check box
6a	The net head of the model turbine is;	$H_n = 14,9$ m	
6b	The net head of the model turbine is;	$H_n = 15,2$ m	
6c	The net head of the model turbine is;	$H_n = 17,3$ m	X
6d	Model turbine efficiency;	$\eta_T = 89,3$ %	
6e	Model turbine efficiency;	$\eta_T = 90,4$ %	
6f	Model turbine efficiency;	$\eta_T = 92,5$ %	X
6g	The flow rate of the prototype is:	$Q_P = 32\ m^3/s$	
6h	The flow rate of the prototype is:	$Q_P = 35\ m^3/s$	X
6i	The flow rate of the prototype is:	$Q_P = 38\ m^3/s$	
6j	The net head of the prototype is:	$H_n = 445$ m	
6k	The net head of the prototype is:	$H_n = 454$ m	X
6l	The net head of the prototype is:	$H_n = 473$ m	
6m	The rotor-stator interaction frequency in the model runner is: Hz	RSI = 175	

6n	The rotor-stator interaction frequency in the model runner is: Hz	RSI = 140	
6o	The rotor-stator interaction frequency in the model runner is: Hz	RSI = 163	X
6p	The rotor-stator interaction frequency in the guide vanes is: Hz	RSI = 175	X
6q	The rotor-stator interaction frequency in the guide vanes is: Hz	RSI = 140	
6r	The rotor-stator interaction frequency in the guide vanes is: Hz	RSI = 163	

Problem 7. Other topics (max. 12 points)

7	(Multiple-choice question)	Check box
A	Which of the following is true regarding erosion of coated turbines?	
i	Coated turbines show erosion pattern like ductile materials	
ii	Coated turbines show erosion pattern like brittle materials	X
iii	Coated turbines show erosion pattern like malleable materials	
iv	Coated turbines show erosion pattern like plastic materials	
B	Which of the following affect the sediment erosion on turbines?	
i	Sediment size	X
ii	Sediment shape	
iii	Sediment concentration	
iv	All of the above	
C	A pelton turbine with a vertical axis of rotation is operating at BEP in steady state. Which of the following statements is true in this situation?	
i	It is not subjected to fatigue because the power output is constant	
ii	It is subjected to fatigue due to the force exerted by the water jet	X
iii	It is subjected to fatigue due to the gravitational force	
iv	It is not subjected to fatigue because it operates at constant rotational speed	
D	In a horizontal axis Francis turbine, which of the following components are usually subjected to fatigue loading?	
i	Runner blades	
ii	Guide vanes	
iii	Turbine shaft	
iv	All of the above	X
E	Which of the following is NOT an environmental impact caused by large scale reservoir type hydropower projects?	

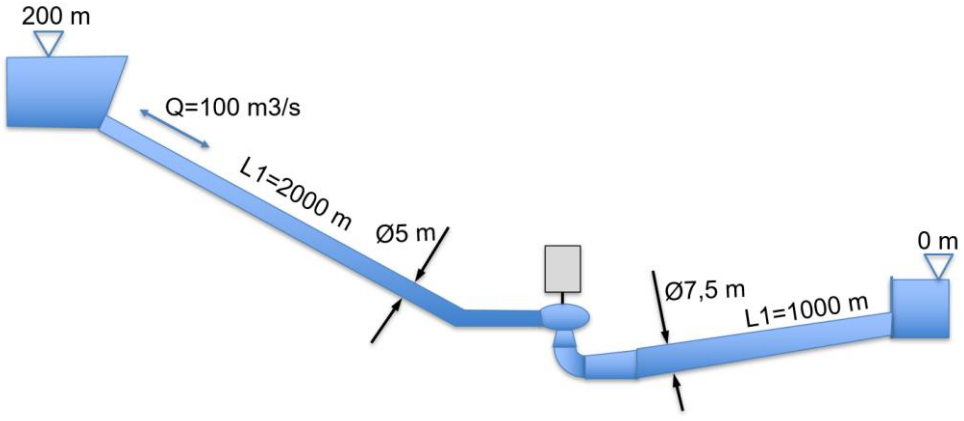
i	Greenhouse gas emission	
ii	Habitat loss	
iii	Sedimentation	
iv	Acid rain formation	X
F	Which of the following statement is False?	
i	A turbine needs to be submerged more if installed in a project at higher elevation compared to that at a lower elevation	
ii	It is easier to cavitate in pump mode than in turbine mode for an RPT	
iii	Cavitation can be detected using the vibration signals from the turbine	
iv	Cavitation is only seen at outlet of Francis turbine runners, where the pressure is relatively lower	X

Problem 8. Head loss in RPT (max. 6 points)

A pumped storage project with Reversible pump turbine has penstock of diameter 5m upstream the turbine and penstock of diameter 7,5m in the tailrace. Assuming that the levels in the reservoirs remain the same and the RPT is working with the same flow in both turbine and pump mode operation, determine the following. Ignore minor losses.

Given data:

	Symbol		Unit
Flow rate	Q	100	m^3/s
Gravity constant	g	9,81	m/s^2
Density of water	ρ	1000	kg/m^3
Diameter of the inlet pipe to the turbine	D_1	5	m
Diameter at outlet of turbine	D_2	7,50	m
Level at the upper reservoir	z_1	200	m
Level at the lower reservoir	z_2	0	m
Coefficient of friction	λ	0,015	
Hydraulic Efficiency in pump mode	η_p	89	%
Hydraulic Efficiency in Turbine mode	η_t	92	%
Generator/motor efficiency	η_G	96	%
Transformer efficiency	η_T	98	%



8	(Multiple-choice question)		Check box
8a	The net head in the turbine mode is;	H_n = 200 m	
8b	The net head in the turbine mode is;	H_n = 191,5 m	X
8c	The net head in the turbine mode is;	H_n = 198,5 m	
8d	The net head in the turbine mode is;	H_n = 185,5 m	
8e	The power supplied to the grid;	P_T = 166,0 MW	
8f	The power supplied to the grid;	P_T = 162,6 MW	X
8g	The power supplied to the grid;	P_T = 239,3 MW	
8h	The power supplied to the grid;	P_T = 187,9 MW	
8i	The power consumed from the grid;	P_p = 239,3 MW	
8j	The power consumed from the grid;	P_p = 244,2 MW	X
8k	The power consumed from the grid;	P_p = 229,8 MW	
8l	The power consumed from the grid;	P_p = 204,5 MW	

Given equations:

Head loss: $h_f = \lambda \cdot \frac{L}{D} \cdot \frac{c^2}{2 \cdot g}$

Head loss: $h_f = \frac{L}{M^2} \cdot \frac{c^2}{R_h{}^{4/3}}$

Hydraulic radius: $R_h = \frac{A}{P}$

Reynolds number: $Re = \frac{c \cdot D}{\upsilon}$

Power output; $P = \rho \cdot g \cdot H_n \cdot Q \cdot \eta$

Frequency of U-tube oscillation: $\omega = \sqrt{\frac{g}{A_{shaft} \cdot {}^{L}/_{A}}}$

Period of U-tube oscillation: $T = \frac{2 \cdot \pi}{\omega}$

Penstock time constant: $T_w = \frac{Q}{g \cdot H} \cdot \Sigma\left({}^{L}/_{A}\right)$

Penstock retardation/acceleration pressure for Tc >>2L/a $\Delta H = \frac{1}{g} \cdot \sum \frac{L}{A} \cdot \frac{\Delta Q}{T_C}$

Up- or down-surge in the surge shaft: $\Delta z = \Delta Q \cdot \sqrt{\frac{\Sigma(L/A)}{g \cdot A_{shaft}}}$

Reduced numbers; $\underline{c} = \frac{c}{\sqrt{2 \cdot g \cdot H}}$ $\underline{u} = \frac{u}{\sqrt{2 \cdot g \cdot H}}$ $\underline{w} = \frac{w}{\sqrt{2 \cdot g \cdot H}}$ $\underline{Q} = \frac{Q}{\sqrt{2 \cdot g \cdot H}}$ $\underline{\omega} = \frac{\omega}{\sqrt{2 \cdot g \cdot H}}$

$\underline{\Omega} = \underline{\omega} \cdot \sqrt{\underline{Q}}$ $n_{ED} = \frac{n \cdot D}{\sqrt{E}}$ $n_q = n \cdot \frac{\sqrt{Q}}{H^{0,75}}$ $Q_{ED} = \frac{Q}{D^2 \cdot \sqrt{E}}$

Affinity equations; $\frac{H_1}{n_1^2 \cdot D_1^2} = \frac{H_2}{n_2^2 \cdot D_2^2}$ $\frac{Q_1}{n_1 \cdot D_1^3} = \frac{Q_2}{n_2 \cdot D_2^3}$ $\frac{P_1}{n_1^3 \cdot D_1^5} = \frac{P_2}{n_2^3 \cdot D_2^5}$

Bernoulli's equation on a turbine: $h_{in} + Z_{in} + \frac{C_{in}^2}{2 \cdot g} = H_n + h_{out} + Z_{out} + \frac{C_{out}^2}{2 \cdot g}$

Net Positive Suction Head, NPSH: $NPSH = h_{atm} - h_v + (z_4 - z_2) + (\varsigma_s - 1) \cdot \frac{c_2^2}{2 \cdot g}$

Turbine efficiency: $\eta = \frac{\omega \cdot M}{\rho \cdot g \cdot Q \cdot H_n}$

Pump efficiency: $\eta = \frac{\rho \cdot g \cdot Q \cdot H_n}{\omega \cdot M}$

Rotor Stator Interaction frequency: $RSI = n \cdot Z$