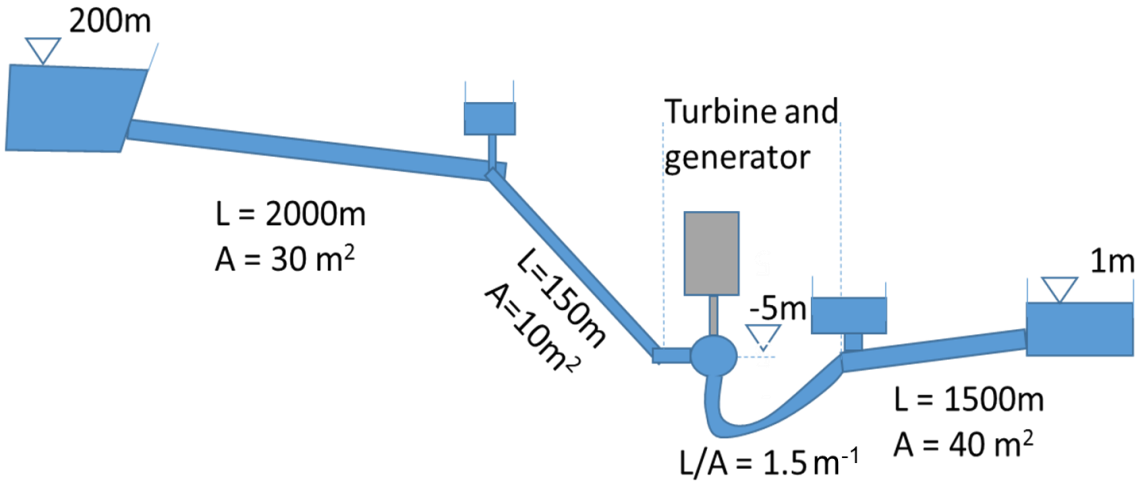
Solution Exam 2024

Problem 1. Turbine and System dynamics

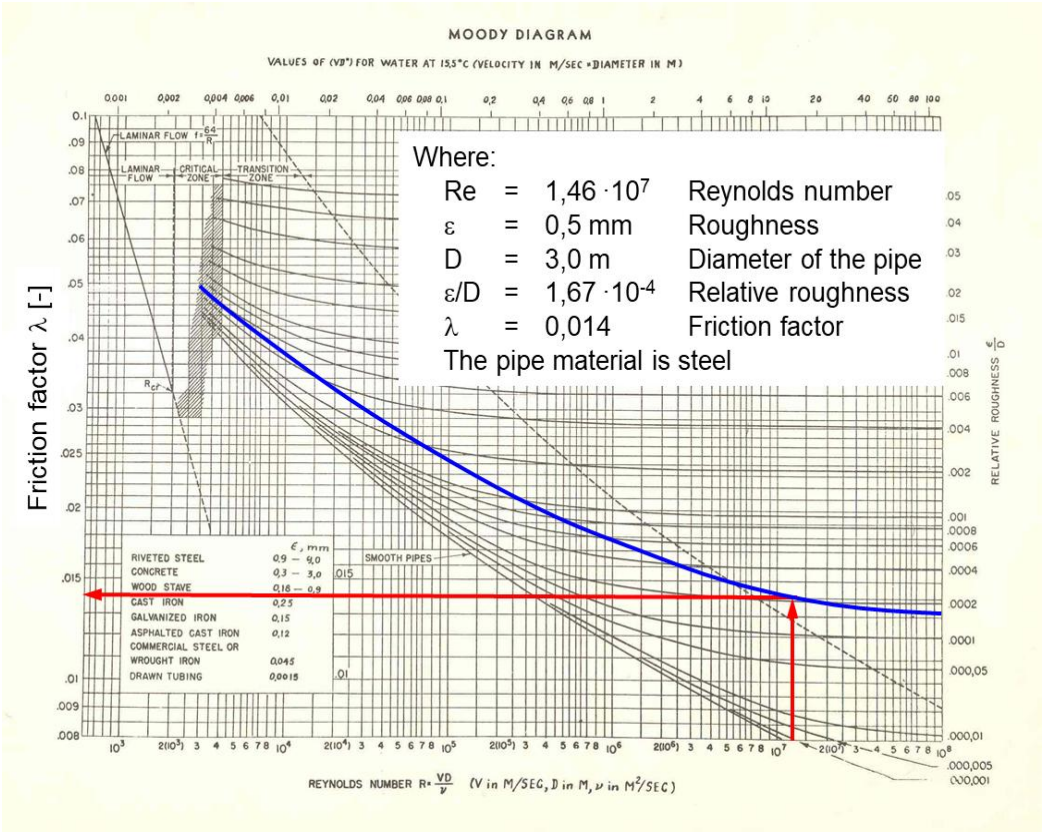
Input data:			
	Head	H	m
	Flow rate	Q	m^3/s
	Number of pole pairs	Poles	
	Upsurge	Δz	m
	Gravity contstant	g	m/s^2
	Length of the upper tunnel	L	m
	Length of the lower tunnel	L	m
	Length of the penstock	L	m
	Area of the upper tunnel	A	m^2
	Area of the lower tunnel	A	m^2
	Area of the penstock	A	m^2
	Area of the surge shaft at the outlet from the draft tube	A	m^2
	L/A for the draft tube	L/A	m^{-1}
	Turbine closing time for 1B and 1 C	T_C	s
	Turbine closing time for 1F	T_C	s
Calculated data:			
1A	Area of the upper surge shaft	A_{Shaft}	m^2
1B	Pressure in the draft tube	ΔH	m
1D	Down surge in the surge shaft at the outlet from the draft tube	Δz	m
	Frequency of U-tube oscillation	ω	rad/s
1E	Period of U-tube oscillation	T	s
1F	Waterhammer upstream the turbine	ΔH	m
	Velocity in the tunnel	c	m/s



Problem 2. Head Loss

Input data:				
	Gross Head	H_G	m	650
	Flow rate	Q	m^3/s	45
	Gravity contstant	g	m/s^2	9,81
	Length of the upper tunnel	L	m	10 000
	Radius of the tunnel	R	m	3
	Height of the tunnel	H	m	3
	Length of the penstock	L	m	1 000
	Diameter of the penstock	D	m	3,0
	Turbine efficiency	η_T		0,94
	Generator efficiency	η_G		0,98
	Transformer Efficiency	η_{Tr}		0,98
	Mannings number	M	$m^{1/3}/s$	34
	Kinetic viscosity	ν	m^2/s	1,308E-06
	Roughness of the penstock	ε	m	0,0005

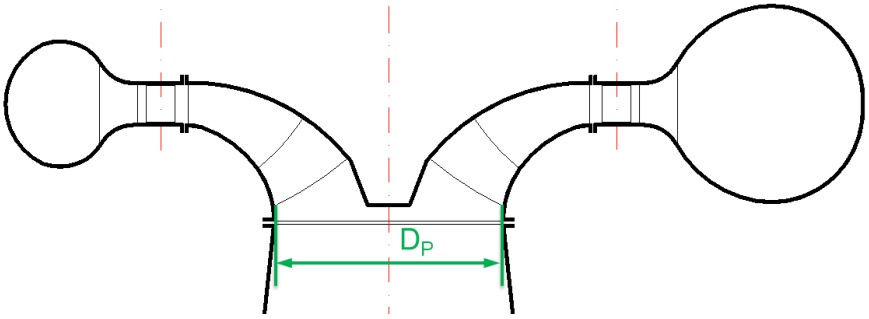
Calculated data:				
	Turbine power output	P_T	MW	262
	Generator power output	P_G	MW	256
	Generator power output	P_{Tr}	MW	251
	Area of the tunnel	A	m^2	32,1
	Area of the penstock	A	m^2	7,1
	Velocity in the tunnel	C	m/s	1,40
	Velocity in the penstock	C	m/s	6,4
	Perimeter of the tunel	P	m	21,4
	Hydraulic radius	R_h	m	1,50
	Head loss in the tunnel	H_f	m	9,88
	Reynolds number in the penstock	Re		1,46E+07
	Relative rougness of the penstock	ε/D		1,67E-04
	Friction factor fromm Moody's diagram	λ		0,014
	Head loss in the penstock	H_f	m	9,6
	Level in the surge shaft		m	640
	Net head	H_n	m	630
	Generator power output at H_G=700 m	P_G	MW	276,7


MOODY DIAGRAM
VALUES OF (VD) FOR WATER AT 15,5°C (VELOCITY IN M/SEC × DIAMETER IN M)
Friction factor λ [-]
RELATIVE ROUGHNESS ε/D
LAMINAR FLOW f = 64/R
LAMINAR FLOW
CRITICAL ZONE
TRANSITION ZONE
Where:
Re = 1,46 ·10^7 Reynolds number
ε = 0,5 mm Roughness
D = 3,0 m Diameter of the pipe
ε/D = 1,67 ·10^-4 Relative roughness
λ = 0,014 Friction factor
The pipe material is steel
ε, mm
RIVETED STEEL 0,9 – 9,0
CONCRETE 0,3 – 3,0
WOOD STAVE 0,18 – 0,9
CAST IRON 0,25
GALVANIZED IRON 0,15
ASPHALTED CAST IRON 0,12
COMMERCIAL STEEL OR WROUGHT IRON 0,045
DRAWN TUBING 0,0015
SMOOTH PIPES
REYNOLDS NUMBER R = VD/ν (V in M/SEC, D in M, ν in M²/SEC)

Problem 4. Francis turbine performance

Input data:				
	Inlet pressure on the model turbine	p_{inlet}	kPa	235
	Outlet pressure on the model turbine	p_{outlet}	kPa	95
	Atmospheric pressure	p_{atm}	kPa	93
	Flow rate on the model turbine	Q_M	m^3/s	0,245
	Gravity contstant	g	m/s^2	9,80
	Density of water	ρ	kg/m^3	1 000
	Velocity at the inlet of the turbine	C_{inlet}	m/s	3
	Velocity at the inlet of the turbine	C_{outlet}	m/s	1
	Level at the inlet	Z_{inlet}	m	1,5
	Level at the outlet	Z_{outlet}	m	1
	Model Turbine Torque	M_T	Nm	900
	Model Turbine Speed	n_M	rpm	350
	Prototype Turbine Speed	n_P	rpm	375
	Generator efficiency	η_G		0,99
	Model Turbine runner outlet diameter	D_M	m	0,35
	Prototype Turbine runner outlet diameter	D_P	m	1,78
	Number of runner blades	Z_{runner}		28
	Number of guide vanes	$Z_{guide\ vanes}$		17

Calculated data:				
	Net Head on the model turbine	H_n	m	15,2
	Turbine Speed	ω	rad/s	36,7
	Turbine Speed - reduced	$\underline{\omega}$		2,1
	Flow rate on the model turbine - reduced	$\underline{Q_M}$		0,014
	Speed number	Ω		0,25
	Turbine power output	P_T	kW	33
	Turbine efficiency	η_T		90,4 %
	Speed factor	n_{ED}		0,17
	Flow factor	Q_{ED}		0,16
	Flow rate on the Prototype turbine	Q_P	m^3/s	35
	Net Head on the prototype turbine	H_n	m	454
	Rotor Stator Interaction	RSI	Hz	99


D_P