Process Automation, mid-term exam, AY. 2016./2017.

Date: 22. November 2016.

Name and surname:___________________________JMBAG:________________________________

Problem 1. (*15 points*)

Into the tank of cross section A, water is poured in with the volume flow of q_u controllable by the valve openness value, x_{vu} (in percentages), with the following characteristic:

$$q_u = k_{vu} x_{vu} \sqrt{\Delta P_u},$$

where k_{vu} is the valve construction design constant and ΔP_u is the difference between input and output valve pressures. At the output of the tank, there is a pump with constant rotational speed, defined with the following law:

$$\Delta P_c = \Delta P_{cm} - \left(\frac{Q_c}{Q_{cn}}\right)^2 (\Delta P_{cm} - \Delta P_{cn}),$$

where Q_c is the output pump mass flow and ΔP_c is the difference between input and output pump pressures. The pressure above the water in the tank is the atmospheric pressure. In order to treat the fluid as the part of the whole process, the given system is required to maintain the specific water level in the tank, where the accessible control variable is the valve openness x_{vu}.

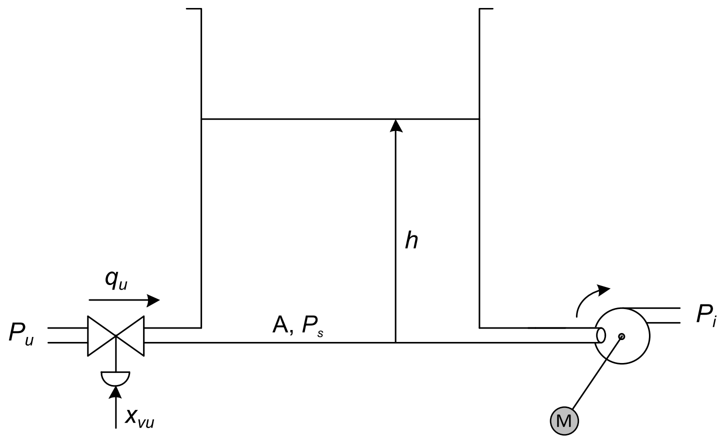

Figure 1. Fluid flow control system

a) (*4 points*) Determine the nonlinear mathematical model of the system and derive differential equations.
b) (*6 points*) Linearize the model at the operating point determined with h_0 = 4.9643 m, x_{vu} = 40% and put it in the form of transfer function $\frac{H(s)}{X_{vu}(s)}$.
c) (*5 points*) By using the PI controller, speed up the process by 10 times. Determine the controller parameters, derive the closed loop transfer function and examine the system stability.

Parameters:

A = 2 m^2	- tank area	ΔP_{cn} = 1.2 bar	- nominal difference of pressures at pump ends
A_c = 0.02 m^2	- cross section of the tank input/output pipes	P_u = 2 bar	- valve input pressure
$k_{vu} = 10^{-3} \frac{m^3}{s\sqrt{Pa}}$	- valve constant	P_i = 3 bar	- pump output pressure
g = 9.81 m/s^2	- gravitational constant	$\Delta P_{cm} = 2\Delta P_{cn}$	- difference of pressures at pump ends with zero flow
ρ = 1000 kg/m^3	- water density	$Q_{cn} = Q_{i0}$	- nominal pump flow

Problem 2. *(15 points)*

Block scheme of the system from Problem 1 is shown in the Figure 2. In order to increase the system reliability, two additional redundant sensors of the water level are introduced and are connected in the static redundancy structure (majority decision 2 of 3). Functionality of PI controller is implemented in the process computer. There is also a redundant computer with the exact same algorithm of the controller, connected with the main computer in the dynamic blind redundancy structure. Mean times between two consecutive faults of each system component are given in Table 1. All of the components have the reliability function of $R(t) = e^{-\lambda t}$ form.

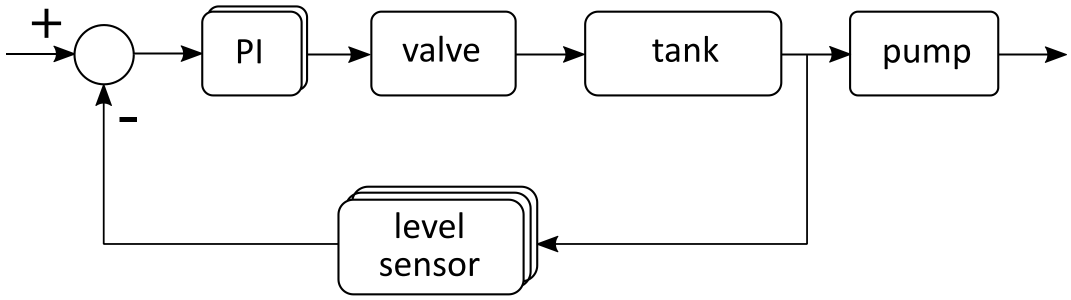

Figure 2. System block scheme

Component	MTBF in days
level measurement sensor (without redundancy)	750
comparison circuit for static redundancy structure	5000
valve	1400
pump	2000
process computer (without redundancy)	2800
tank	10000

Table 1. MTBF of system components

a) *(4 points)* Derive the reliability function of level measurement sensors in the static redundancy structure.
b) *(6 points)* Derive the reliability function of PI controllers in dynamic blind redundancy structure.
c) *(3 points)* Derive the reliability function of the whole system.
d) *(2 points)* What is the probability that the system will function properly after 1 year of operation?