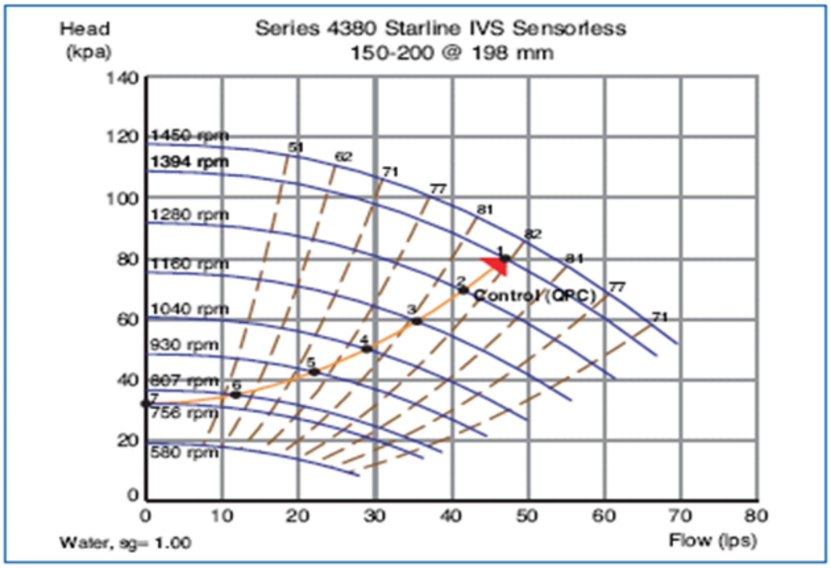


Figure 1: ARMSTRONG 4380 water pump

Pump

With ARMSTRONG 4380 water pump the system pressure is kept 70 kPa where water consumption varies between (10 .. 50) L / s. [curved arrow in the figure is not included into the task]

Pump speed $n = (0 - 1500)\ r/min$ controlled by a linear frequency converter with control signal $u = 0$ ...100%.

Determine the control signal u range and a block (frequency converter + pump) gain K value and its range.

Comments

1 Industrial pumps

Most liquids are moved by industrial pumps. Pumping costs consist of

- 5% of capital expenditures,
- 10-15% of exploitation,
- 85% of the energy cost ($\approx$ 100x more than the price!)

Industrial pumps use 20% of the power generated (paper, chemical and petrochemical industries, up to 30 ... 50%).

Pumps with higher efficiency (with engines) is 60-80%, significantly affects the cost.

View:

`http://www.PumpLearning.org`
`http://www.pumps.org`
`http://www.pumpsystemsmatter.org`
`http://www.pump-zone.com`
`http://www.engineeringtoolbox.com`

Where the energy goes during the pumping?

1. Potential energy

   pressurized liquid P, rises on the height H

   work $A_p = mg \cdot H = V\rho g H = VP$, where V - volume, P - pressure, Q-consumption

   Power $N_p = A_p/t = QP = 4000\ W$

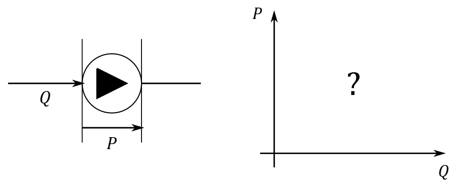
2. Kinetic energy

   Energy $A_k = mv^2/2$, where v - fluid velocity ($2\ m/s$)

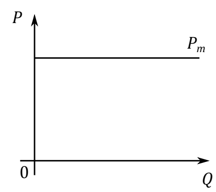
   Power $N_k = qv^2/2 = 20\ W$ during the pumping `pot.energy` $\rightarrow$ `kin. energy`!

3. Losses (due to change in flow rate and direction) $\sim$ 10%.

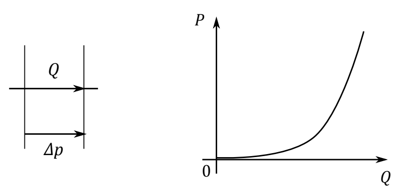
2 Pump characteristics



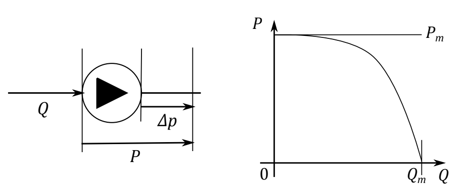
- Ideal pump $P = P_m$



- fluid flow $\Delta p \sim Q^2$, $\quad \Delta p = k \cdot Q^2$ turbulent



- real pump `-centrifugal pump-` internal resistance: Opening $S(m^2)$ IMPELLER



$P = P_m - \Delta p$; $F(P, Q) = 0$; analogy with an electric battery, but nonlinear

$$P = P_m - k \cdot Q^2 \quad (1)$$

maximum flow Q_m

$$P = P_m[1 - (Q/Q_m)^2] \quad (2)$$

When the pump develops maximum power?

power $N = P \cdot Q = (P_m m - k \cdot Q^2)Q$ *max* N? $\mathrm{d}N/\mathrm{d}Q = 0 \to (P_z, Q_z)$

The maximum capacity of the pump at operating point $P_z = 2/3 P_m, \quad Q_z = 1/\sqrt{3} \cdot Q_m$

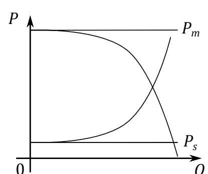
pump (engine!) has a limited capacity

$$P = 3/2 \cdot P_z[1 - 1/3(Q/Q_Z)^2] \quad (3)$$

Is it a max performance too?

Pump curve $F(P, Q) = 0$ is represented by two parameters

- real pump + external resistance (load)

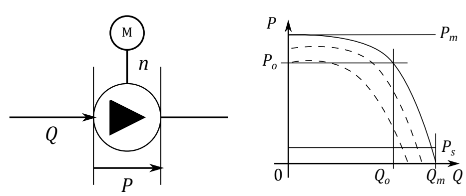


Operating point (P, Q), the pump characteristic is designated by the load and changes due to the load change.

Variable rotational speed n, $P_m \sim n^2$ parameters:

$F(P, Q, N) = 0, \quad P = k_1 \cdot n^2 - k_2 \cdot Q^2 \qquad (k_1, k_2)$

$$P = \ldots (n/n_o)^2 \qquad (\ldots n_o) \quad (4)$$



3 Calculations

Calculate coefficients k_1 and k_2 from the equation $P(Q, n) = k_1 \cdot n^2 - k_2 \cdot Q^2$ with rotation speed $n = 1450\ r/min$

Do these parameters describe other pump speeds?

1. calculate in Excel the pump equation $P(Q, n)$ values as a function of $Q = 0, 10, 20, \dots, 70 L/s$ (line),with the parameters $n = 1450, 1394, \dots$ (Column)

2. provide data by figure; place one on the other: task's and Excel figures, assess the match, adjust the parameters k_1, k_2.

Pressure P control $P = P_o$ by rotation speed n due to consumption Q changes. $n = F_1(P_o, Q)$
n-range $n_{\max} \dots n_{\min}$
gain $K_p = \mathrm{d}P/\mathrm{d}n$