Modeling of a regenerative System

Modes of Operation

(1) Electric motor is on & the magnetic clutch is disengaged (off)

(a) Starting mode

at first the inertia of the motor must appear in the system

(b) normal operation mode

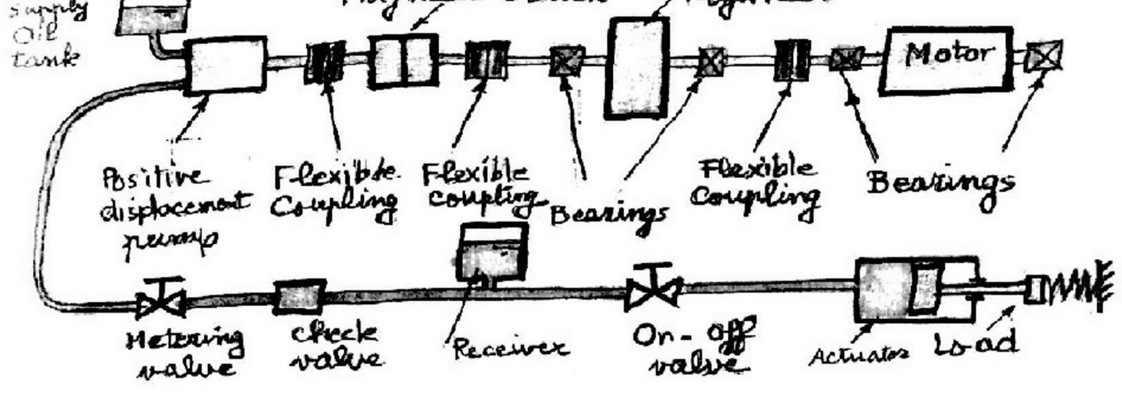
The motor drives the flywheel through a flexible coupling which store this energy.

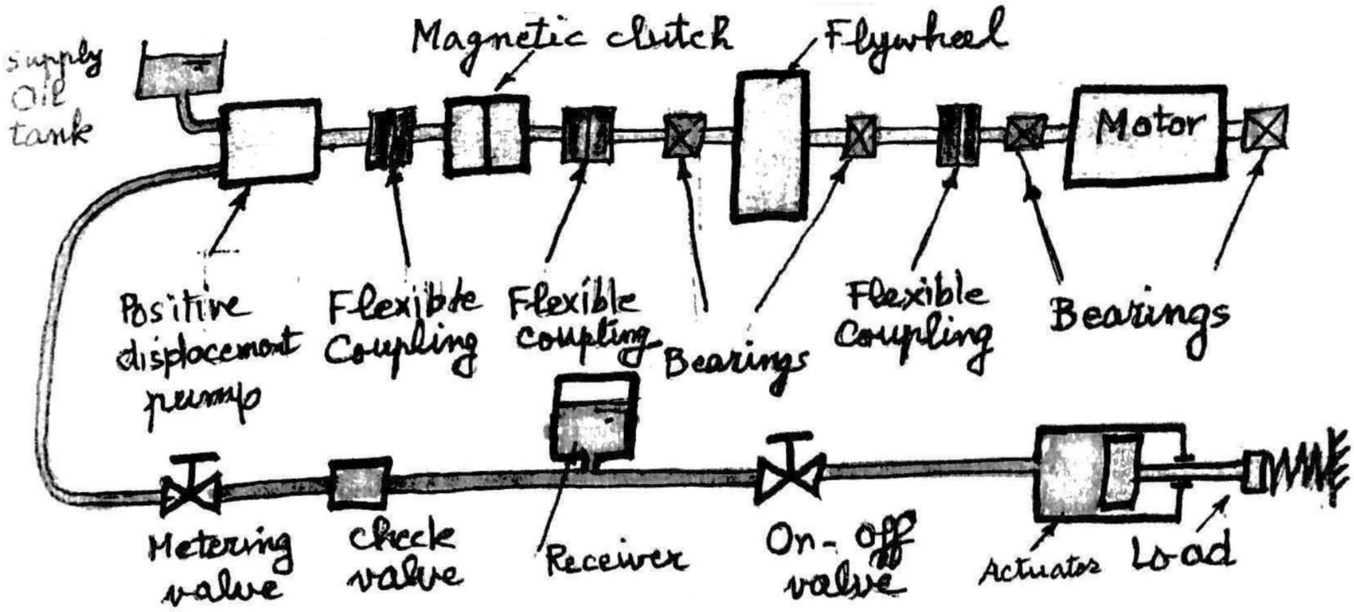
(2) Electric motor is off and magnetic clutch is engaged (on)

in this position the flywheel discharge its stored energy to drive the positive displacement pump which generates the necessary hydraulic power to charge the receiver and no flow in the Actuator side as the on-off valve in the closed position.

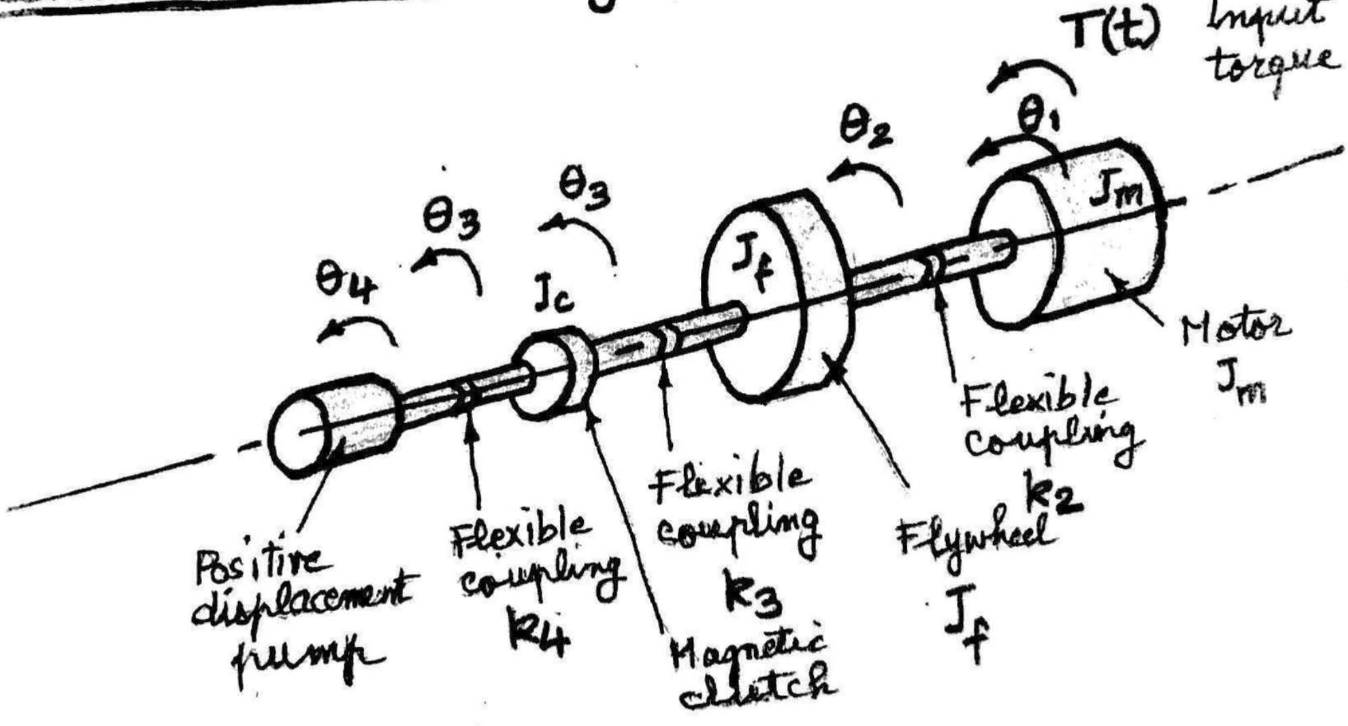
(3) Receiver is full & Pump is off and no energy in flywheel

here the receiver discharge the stored hydraulic under pressure to linear motion in the actuater as on-off valve in the open position.





Mechanical rotational system:



Magnetic clutch off:

$$T(t) + k_2(\theta_{02} - \theta_{01}) = J_m \ddot{\theta}_{01} \qquad \text{——— (1)}$$

$$-k_2(\theta_{02} - \theta_{01}) = J_f \ddot{\theta}_{02} \qquad \text{——— (2)}$$

Initial conditions:

$t = 0$, $\theta_{01} = \theta_{02} = \dot{\theta}_{01} = \dot{\theta}_{02} = 0$

To be solved for θ_{01} & θ_{02} in the domain

$t = 0 \rightarrow t_0$

"Some general comments"

$$T(t) + k_2(\theta_{02} - \theta_{01}) = J_m \ddot{\theta}_{01} \quad \text{——} (1)$$

$$-k_2(\theta_{02} - \theta_{01}) = J_f \ddot{\theta}_{02} \quad \text{——} (2)$$

Initial conditions:

$t = 0$, $\theta_{01} = \theta_{02} = \dot{\theta}_{01} = \dot{\theta}_{02} = 0$

Simplified solution:

Assume a simple form of induction motor,

$$\boxed{\dot{\theta}_{01} = \omega_m (1 - e^{-t/t_0})} \quad \text{——} (3)$$

and $T(t) = T$ —— (4)

Adding eqn. (1) and (2)

$$T(t) = J_m \ddot{\theta}_{01} + J_f \ddot{\theta}_{02} \quad \text{——} (4)$$

Assuming the stiffness of the couplings to be rigid enough to let $\dot{\theta}_{02} \simeq \dot{\theta}_{01}$ and consequently $\ddot{\theta}_{02} = \ddot{\theta}_{01}$

Eqn. (4) becomes,

$$T(t) = (J_m + J_f)\ddot{\theta}_{02} \quad \text{——} (5)$$

From eqn (5)

$$\ddot{\theta}_{02} = \frac{T}{J_m + J_f} \quad \text{——} (6)$$

Integrating eqn. (3) once we have,
with $\dot{\theta}_{01} = \dot{\theta}_{02}$:

$$\theta_{02} = \omega_m(t + t_0 e^{-t/t_0}) + c_1$$

with $\theta_{01}(0) = 0$, we have,

$$\theta_{02} = \omega_m (t + t_0 e^{-t/t_0} - t_0) \text{ ——— } (7)$$

But from eqn. 3 :

$$\ddot{\theta}_{02} = \frac{\omega_m}{t_0} e^{-t/t_0} ,$$

Assuming constant acceleration at start,

$$\ddot{\theta}_{02} = \ddot{\theta}_{02}(0) = \frac{\omega_m}{t_0} ,$$

Therefore from eqn. (6) we have,

$$\frac{T}{J_m + J_f} = \frac{\omega_m}{t_0}$$

Therefore,

$$\omega_m = \frac{T t_0}{J_m + J_f}$$

Eqn(7) becomes,

$$\boxed{\theta_{02} = \frac{T t_0}{J_m + J_m} (t + t_0 e^{-t/t_0} - t_0)} \text{ ——— } (8)$$

Note: The rest of the program in Simulink is for the Mechanical and pump system.

Magnetic clutch on :

$$k_2(\theta_2 - \theta_1) = J_m \ddot{\theta}_1 \quad \text{———— (3)}$$

$$-k_2(\theta_2 - \theta_1) + k_3(\theta_3 - \theta_2) = J_f \ddot{\theta}_2 \quad \text{——— (4)}$$

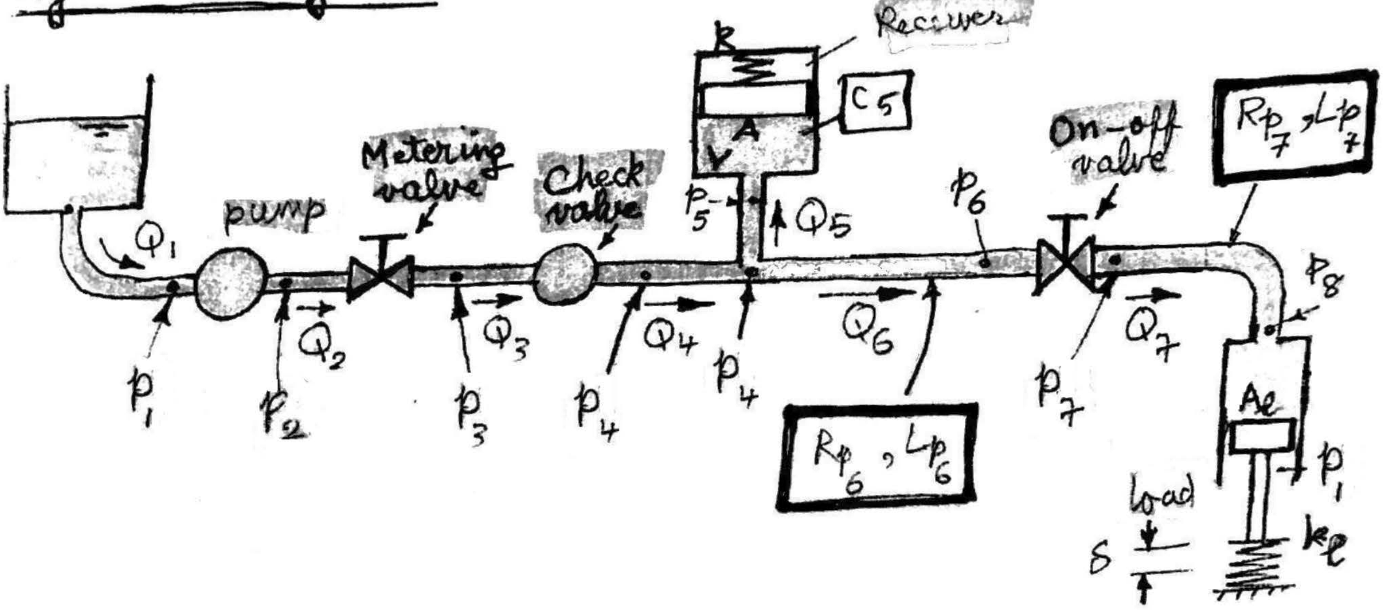
$$-k_3(\theta_3 - \theta_2) + k_4(\theta_4 - \theta_3) = J_c \ddot{\theta}_3 \quad \text{——— (5)}$$

Initial conditions :

$t = t_0$, $\theta_1 = \theta_{01}$, $\theta_2 = \theta_{02}$, $\theta_3 = 0$, $\theta_4 = 0$,

$\dot{\theta}_1 = \dot{\theta}_{01}$, $\dot{\theta}_2 = \dot{\theta}_{02}$, $\dot{\theta}_3 = 0$, $\dot{\theta}_4 = 0$.

Hydraulic system



note

k_2 , k_3 , k_4 : stiffness of flexible coupling

J_m , J_f , J_c , J_p : moment of inertia of motor, flywheel, clutch and pump

k_m , k_c , k_v : valve coefficients of metering , check, on-off valves

A : Receiver Area (m^2) , k_r : receiver spring stiffness

k_l : Actuator spring stiffness , m: piston mass , P_1 : Atmospheric pressure

* The eqns. used in the case of on-off valve closed are :

1- The pressure at inlet to the pump is assumed atmospheric to avoid any sort of negative pressure at inlet to the pump to avoid cavitation.

2- The equation for the efficiency of the pump was corrected to become,

$$\boxed{\frac{(P_2 - P_1)\,Q_2}{\dot{\theta}_4\,\eta_t} - k_4(\theta_4 - \theta_3) = J_p\,\ddot{\theta}_4} \quad \text{— (1)}$$

— (2)

$$Q_3 = \frac{1}{k_m}\sqrt{|P_2 - P_3|} \quad (3)$$

$$Q_4 = \frac{1}{k_c}\,|P_3 - P_4| \quad (4)$$

with $Q_3 = Q_4 = Q_5$ — (5)

$$Q_5 = C_5(\dot{P}_4 - \dot{P}_5) \quad \text{with } C_5 = \frac{A^2}{k_r}$$

$Q_6 = Q_7 = 0$ (On_off valve closed) — (6)

* The equations in the case of on-off valve opened are : (1)

$$\ddot{S} = (P_8 - P_1)\frac{A_e}{m} - \frac{k_e}{m}S$$

* Compressibility of the fluid is assumed negligible $B=0$, in order to eliminate the problems associated with compressibility. Therefore, Q_5 is to be calculated from:

$$Q_5 = A_\ell \dot{\delta} \qquad (2)$$

$$P_6 = P_4 - L_{p_6} \dot{Q}_5 - R_{p_6} Q_5 \qquad (3)$$

$$P_7 = P_6 - (Q_5 k_v)^2 \qquad (4)$$

$$P_8 = P_7 - L_{p_7} \dot{Q}_5 - R_{p_7} Q_5 \qquad (5)$$

$$\text{with } P_5 = P_4 \qquad (6)$$

* It seems that the problem is apparently working but it needs further investigations.

* The problem also needs more reliable experimental data.

$L_{p_6} = \dfrac{\rho\, l_{p_6}}{A_{p_6}}$ — l_{p_6} : pipe (6) length, A_{p_6} : pipe(6) Area — & ρ : Hydraulic oil density

$L_{p_7} = \dfrac{\rho\, l_{p_7}}{A_{p_7}}$ — l_{p_7} : pipe (7) length, A_{p_7} : pipe (7) Area

$R_{p_6} = \dfrac{128\, \mu\, l_{p_6}}{\pi\, d_{p_6}^4}$ — μ : Dynamic oil viscosity, d_{p_6} : pipe (6) diameter

$R_{p_7} = \dfrac{128\, \mu\, l_{p_7}}{\pi\, d_p}$ — d_{p_7} : pipe (7) diameter