Design of inner current loop controller and outer speed loop controller for two loop DC motor drive system

I. Modeling and design method of the DC drive and its control system

The separately excited DC machine can be represented in block diagram as shown in Figure 1. V_a, i_a, L_a, R_a, L_m, I_f, J, T_e, T_L and ω_m are the applied armature voltage, armature current, armature inductance, armature resistance, mutual inductance between armature and field winding, fixed field current, mechanical inertia, electromagnetic torque of the machine, applied load torque and speed of the machine respectively. The block diagram shown in Figure 1 can be derived from the equations of the machines as shown in Eqn 1.

$$\begin{aligned} &V_a = R_a i_a + L_a \tfrac{di_a}{dt} + L_m I_f \omega_m \\ &Te = L_m I_f i_a \\ &J \tfrac{d\omega_m}{dt} = T_e - T_L \end{aligned} \tag{1}$$

So, the armature voltage is controlled by a chopper where, the duty cycle (D) of the chopper is controlled to control the output voltage (armature voltage) of the chopper according to the equation shown Eqn 2. Where, V_{dc} is the input voltage of the chopper.

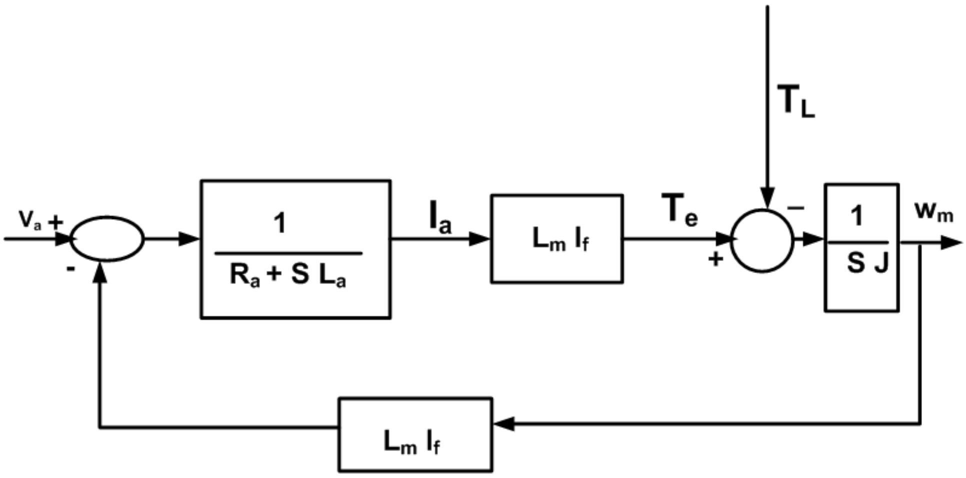

Fig. 1. Schematic block diagram of the separately excited DC motor

$$V_a = V_{dc}\, D \tag{2}$$

II. Design of internal current loop

So, the two loop control is done in such a way that the internal current loop is 10 times faster than the outer speed loop. This facilitates the possibility to make mechanical speed loop to be much slower than the current dynamics of the machine. So, in designing the current loop PI controller, the back emf ($L_m\, I_f\, \omega_m$)feedback, as shown in Figure 1, can be opened and the resultant block diagram can be drawn as shown in Figure 2. So, if the condition stated in Eqn 3 can be satisfied, the resultant open loop transfer function of the current loop can be written as shown in Eqn 4.

$$\frac{K_{ii}}{K_{pi}} = \frac{R_a}{L_a} \tag{3}$$

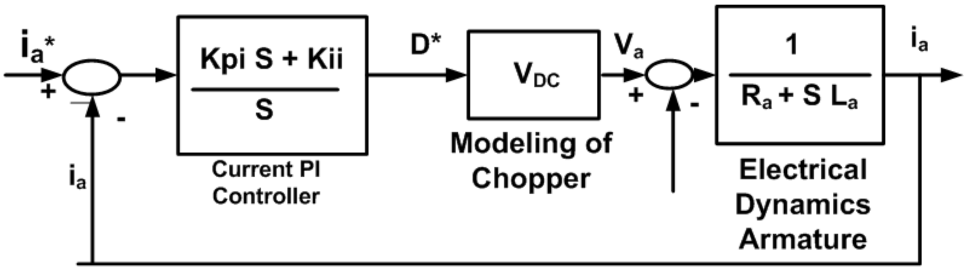

Fig. 2. Approximated current control loop

$$G_{OL_{cur}}(S) = \frac{K_{pi}\,V_{dc}/L_a}{S} \tag{4}$$

So, if the switching frequency of the chopper is f_s, then the open loop BW of $G_{OL_{cur}}(S)$ should be set to be $f_{cur} \leq \frac{f_s}{10}$. This condition is represented in Eqn 5.

$$\frac{K_{pi}\,V_{dc}}{L_a} = 2\,\pi\,f_{cur} \tag{5}$$

So, Eqn 3 and 5 can be solved to get the parameter so the current Pi controller parameters.

III. Design of external speed loop

The BW of the speed control loop is to be designed to have 10 times slower pole than current loop. So, during design of the speed loop PI controller gains, it can be assumed that the speed PI controller output (current reference) is immediately followed (in Figure 3, this assumption is represented as $i_a^* = i_a$). So, the speed Pi controller can be approximated as shown in Figure 3. K_w is the gain of the speed sensor.

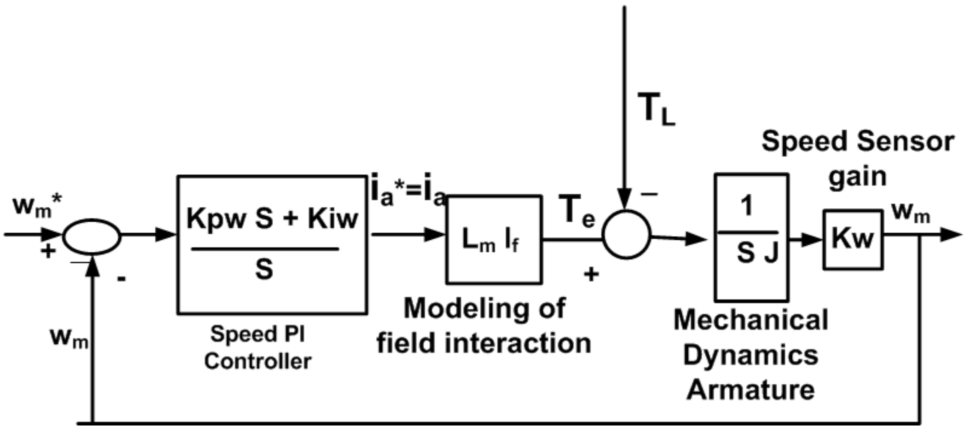

Fig. 3. Approximated speed control loop

Now the open loop transfer function of this speed control loop can be written as as shown in Eqn 6.

$$G_{OL_{speed}}(S) = \frac{S\,K_{pw} + K_{iw}}{S}\,K_m\,\frac{1}{J\,S}\,K_w = \frac{1 + S\,\tau}{S^2}\,K_a \tag{6}$$

Where, $K_m = L_m * I_f$, $\tau = \frac{K_{pw}}{K_{iw}}$ and $K_a = \frac{K_m\,K_w\,K_{iw}}{J}$. So, the closed loop transfer function of speed loop can be written as shown in Eqn 7.

$$G_{CL_{speed}}(S) = \frac{(1 + S\,\tau)\,K_a}{S^2 + S\,K_a\,\tau + K_a} \tag{7}$$

Eqn 7 can be rearranged as shown in Eqn 8.

$$G_{CL_{speed}}(S) = \frac{(S+\frac{1}{\tau})\,K_a\,\tau}{S(S+\frac{1}{\tau}) + S(K_a\,\tau - \frac{1}{\tau}) + Ka} \tag{8}$$

If $\tau^2\,K_a >> 1$ is ensured by design, then it can be written that, $\frac{K_a\,\tau}{k_a\,\tau^2-1} \cong \frac{1}{\tau}$, This design criterion changes the shape of $G_{CL_{speed}}(S)$ by stable pole-zero cancelation as shown in Eqn 9.

$$G_{CL_{speed}}(S) = \frac{K_a\,\tau}{S + K_a\,\tau - \frac{1}{\tau}} \tag{9}$$

So, the speed loop is approximated to a single pole system only. Thus the close loop pole of the speed loop is set at f_{sp} such that $f_{sp} = \frac{f_{cur}}{10}$. These conditions can be written together in Eqn 10.

$$\begin{aligned} &(K_a\,\tau - \tfrac{1}{\tau}) = 2\,\pi\,f_{sp} \\ &\tau^2\,K_a = 100 \end{aligned} \tag{10}$$

Eqn 10 can be solved to get the controller parameters of the speed loop.