1. The state diagram of a rotational system is shown in **Fig. A**. The state variables have been defined in the figure. (1) Write the state equation from the state diagram.【計分：5 分】 (2) Using Mason's Gain Formula, find the transfer functions $\Theta_1(s)/T(s)$ and $\Theta_2(s)/T(s)$ for the system.【計分：10 分】

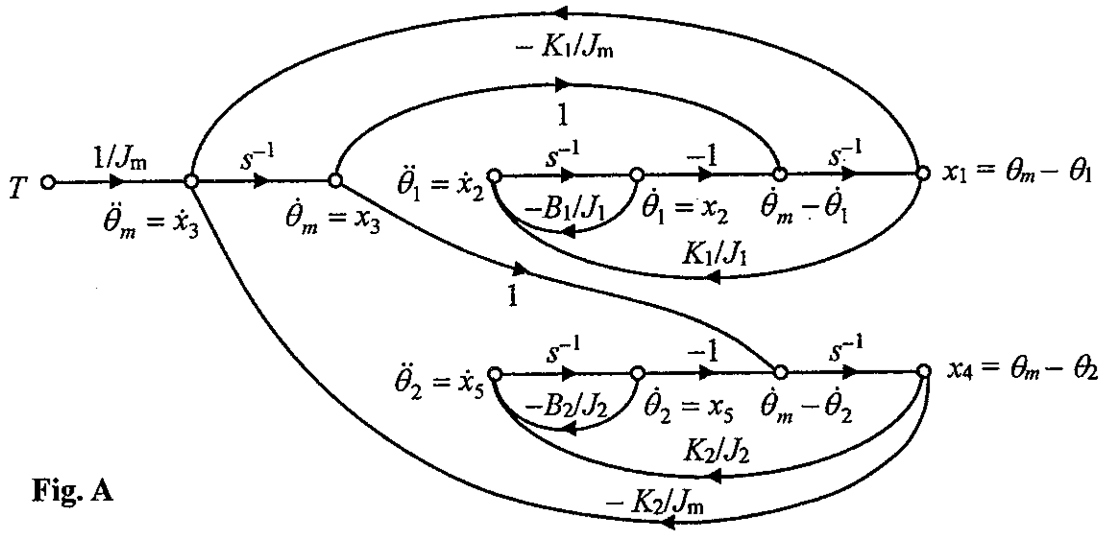

Fig. A

2. A double-inverted pendulum can be approximately model by the following linear state equation:

$$\frac{d\mathbf{x}}{dt} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 16 & 0 & -8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ -16 & 0 & 16 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}\mathbf{x} + \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}u(t)$$

Determine the controllability of the system.【計分：15 分】

3. The schematic diagram of a feedback control system using a dc motor is shown in **Fig. B**. The torque developed by the motor is $T_m(t) = K_i\, i_a(t)$, where K_i is the torque constant. The parameters of the system are: $K_s = 2$; $R_a = 0.1\ \Omega$; $R_s = 0.1\ \Omega$; $K_b = 4.8$ V/rad/sec; $K_i = 5$ N-m/A; $K = 2$; $L_a \cong 0$ H; $J_m + J_L = 10$ N-m-sec^2; $B_m \cong 0$ N-m-sec. Assume that all the units are consistent so that no conversion is necessary. (1) Let the state variables be assigned as $x_1 = \theta_y$ and $x_2 = d\theta_y/dt$. Let the output be $y = \theta_y$. Write the state equation in vector-matrix form. Show that the matrices **A** and **B** are in CCF (Controllability Canonical Form).【計分：4 分】(2) Let θ_r be a unit-step function. Find $\mathbf{x}(t)$ in terms of $\mathbf{x}(0)$, the initial state.【計分：8 分】(3) Find the characteristic equation, eigenvalues, and eigenvectors of **A**.【計分：6 分】(4) Comment on the purpose of the feedback resistor R_s.【計分：2 分】

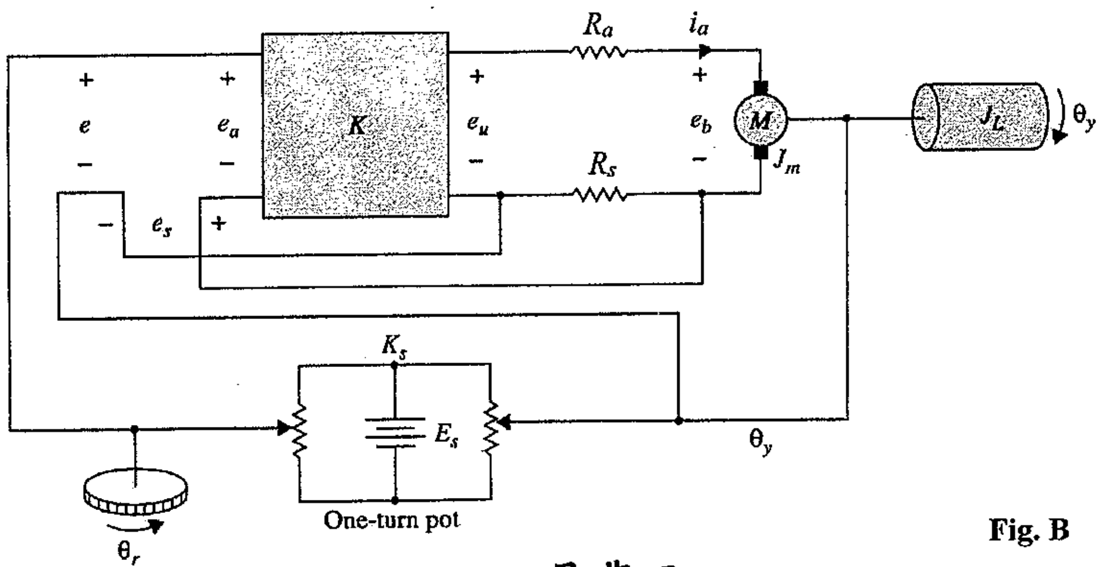

Fig. B

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4. Consider the simplified model the DC motor employing proportional feedback as shown in **Fig. C**. Using the parameter values: $\tau=1$, $A=1$, $K_I=1$, determine the system type and steady state error (expressed in terms of K) with respect to (1) step reference【計分：10 分】, (2) step disturbance【計分：10 分】, (3) ramp reference inputs【計分：5 分】.

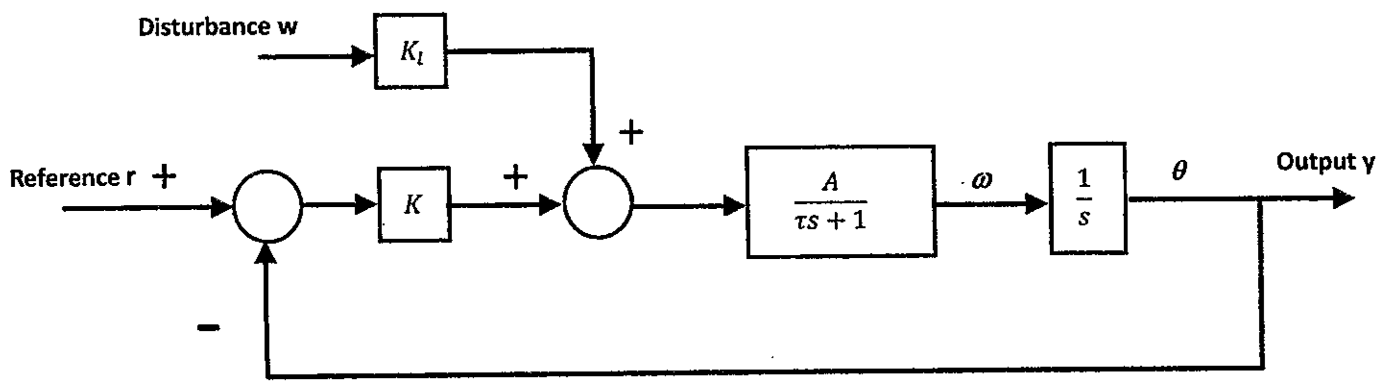

Fig. C

5. Automatic ship steering is particularly useful in heavy seas when it is important to maintain the ship along an accurate path. Such a control system for a large tanker in shown in **Fig. D,** with the transfer function relating heading changes to rudder deflection in radius.

(1) Write the differential equation that relates the heading angle to rudder angle for the ship **without** feedback【計分：5 分】.

(2) This control system uses simple proportional control and has the gain K=1. Please use Routh's criterion to determine its stability【計分：5 分】.

(3) Please determine the range of the gain K so that the system is stable【計分：5 分】.

(4) Try to design a controller for the ship steering system so that the resulting closed-loop system is stable, and in response to a step heading command has zero steady-state error and less than 10% overshoot【計分：10 分】.

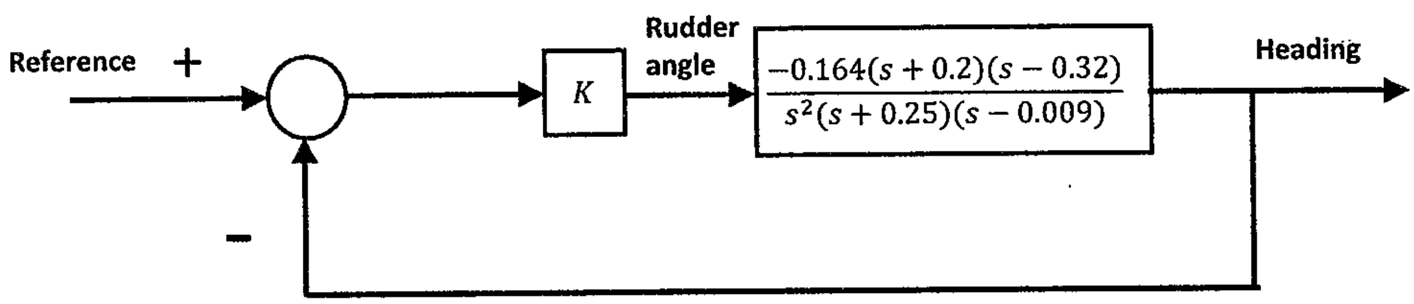

Fig. D

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