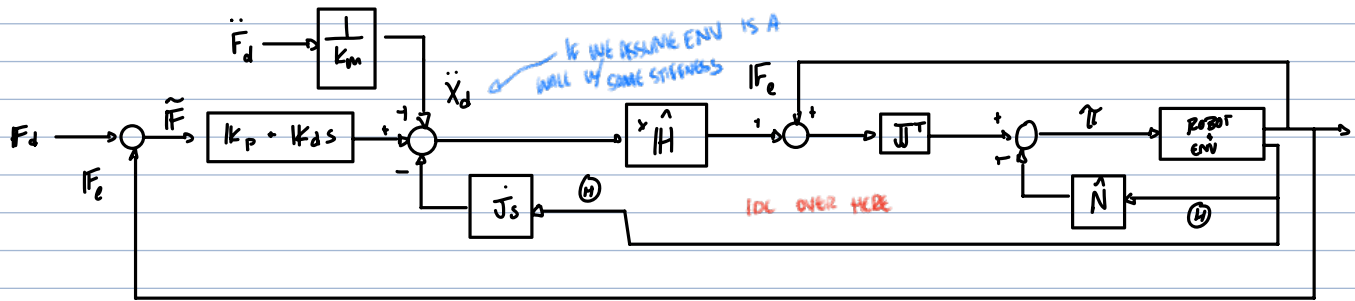


21 DIRECT FORCE CONTROL

WE WANT TO SPECIFY A DESIRED FORCE & USE FORCE FEEDBACK TO MAKE ACTUAL FORCE \Rightarrow DESIRED FORCE



F_d IS USUALLY CONST
 $\sim \dot{F}_d$ USUALLY 0

$$\hat{H} = J^{-T} \hat{H} J^{-1}$$

1. WE DON'T ALWAYS KNOW WALL STIFFNESS K_w , SO WE TYPICALLY LEAVE OUT \ddot{F}_d COMPENSATION

2. F_e IS TYPICALLY NOISY, SO DIFFERENTIATION IS USUALLY ILL-ADVISED.

• PV CONTROL IS BETTER THAN PD

• PENALIZE VELOCITY, NOT FORCE DERIVATIVE

• WE NEED DERIVATIVE CONTROL TO ADD DAMPING TO SYSTEM

3. Ideally $\tilde{F} = F_d - F_e = 0$ @ EQUILIBRIUM, BUT IF WE HAVE AN UNMODELLED DISTURBANCE THEN $\tilde{F} \neq 0$

0.1. DYNAMICS

$$\tau = H \ddot{\theta} + N + J^T F_e + J^T F_{dist}$$

Annotations:

- "DISTURBANCE FORCE" points to $J^T F_{dist}$.
- "PHYSICAL FORCE FEEDBACK" points to $J^T F_e$.

(1) QUASI-STATIC CASE (PUSHING AGAINST WALL)

$$\tau = H \ddot{\theta} + N + J^T F_e + J^T F_{dist}$$

Annotations:

- $\ddot{\theta} \rightarrow 0$ (quasi-static assumption)
- $N \rightarrow G$ (gravity)

(2) CONTROL LAW:

$$\tau = \hat{N} + J^T F_e + J^T \hat{H} K_p \tilde{F} \quad (\text{QUASI-STATE})$$

(1) + (2) \Rightarrow C.L. DYNAMICS

$$\cancel{\hat{G}} + J^T F_e + J^T \hat{H} K_p \tilde{F} = \cancel{G} + J^T F_e + J^T F_{dist}$$

$$\tilde{F} = (\hat{H} K_p)^{-1} F_{dist}$$

AT EQUILIBRIUM $\tilde{F} \neq 0$ (STEADY STATE FORCE ERROR BAD)

The block diagram shows a control system with the following components and connections:

- Inputs:** A reference signal F_d and a disturbance signal F_e .
- Summing Junction 1:** The reference signal F_d is added (+) and the disturbance signal F_e is subtracted (-) to produce the error signal \tilde{F} .
- Controller:** The error signal \tilde{F} is processed by a proportional controller block labeled K_P .
- Summing Junction 2:** The output of the K_P block is added (+) and the feedback signal x is subtracted (-) to produce the control signal.
- Plant:** The control signal is processed by a block labeled K_d .
- Integrator:** The output of the K_d block is integrated by a block labeled J (representing $\frac{1}{s}$).
- Derivative Block:** The output of the integrator is differentiated by a block labeled $\frac{d}{dt}$.
- Feedback:** The output of the derivative block is the system output Θ , which is also the feedback signal x fed back to the second summing junction.

The diagram shows a control system with the following components and connections:

- Inputs:** F_d (desired force) and F_e (error force).
- Feedforward Path:** F_d is summed with F_e to produce \tilde{F} . This signal passes through a gain block k_p and is summed with the feedback signal to produce the control signal u .
- Plant:** The control signal u is the input to the plant, represented by a block \hat{H} .
- Feedback Path:** The plant output y is fed back through a block J^T and summed with \tilde{F} to produce the error signal e .
- Derivative Feedback:** The error signal e is also fed into a derivative feedback path consisting of a block k_D , an integrator \int , and a derivative block $\frac{d}{dt}$. The output of this path is summed with u to produce the final control signal u .
- Disturbance Estimation:** The error signal e is also fed into a disturbance estimator block \hat{N} , which is part of a "proportional control" loop. The output of this loop is summed with u to produce the final control signal u .

$$\hat{u} = \hat{N} + J^T F_d + J^T \times \hat{H} K_p F \quad (\text{QUASI-STATIC})$$
$$\tilde{F} = (\mathbf{I} + \alpha \hat{H} K_p)^{-1} F_{\text{dist}}$$

INVERSE OF A LARGER THING BECOMES A SMALLER THING