INTRODUCTION 7-8-85

These notes will discuss control theory aspects of the head positioning servo system of disc memories. The eventual goal of the research is to achieve a system design returning optimum seek, ~~and~~ settle, and track follow performance in high track density, multiple data head disc memories. In the context to be used here, optimum performance means achieving minimum seek and settle times subject to a set of constraints which will include limits on available power and component variations with time and temperature. Other reasonable system constraints will be imposed as the need arises. Track following error is to be minimized within these same constraints.

As a research vehicle, I have available a number of linear voice coil actuators. As a result, I expect some experimental work to be carried out using these components. However, this study must also consider the behavior of rotary voice coil actuators inasmuch as rotary actuators are of considerable economic importance.

Much work has been carried out in both industry and the literature pertaining to servo control systems based on the transfer function approach. I shall cite sources where appropriate. ~~In addition~~ In addition, some work has been carried out using hybrid analog/digital methods with some amount of state variable theory employed. I am not aware of any extensive modern control theory work based on the observer method of Luenberger [1] or the theory of stochastic observers [2] that has been applied to disc memory systems. Since it seems quite likely that an optimum controller would require VLSI implementation if it is to be economically justifiable, I shall concentrate my efforts in the area of state variable control using the stochastic observer method with the intent of synthesizing a discrete Kalman filter implementation.

I suspect that for a mechanism that can be adequately modeled as a linear, time-invariant (LTI) system, present practice approaches the optimum. The problems with practical systems are most likely to be encountered in the form of friction, variation of system parameters, interference and noise, nonlinear thermal effects, transducer imperfections, and external disturbances.

[2] Ibid pp 327-347

[1] Applied Optimal Estimation, A. Gelb (ed), pp 321-327 (MIT Press, 1974)

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Model of a Servo System 7-10-85

The servo problem can be decomposed as illustrated in figure 1. The thing to be controlled is the mechanism, M. The mechanism accepts as inputs a control signal $I_a(t)$ as well as uncontrolled external forces such as gravity, vibrations, or physical shocks. ~~and~~ Normally, these external factors are not directly observable by the controller, S. One possible approach to this difficulty is to treat F as a colored ~~noise~~ stochastic input. ~~The first~~ Among the many tasks to be undertaken is the appropriate modeling of this stochastic input so that the closed loop system may be ~~evaluated~~ operated over some specified dynamic input range.

The outputs of M consists of a set of positions $X(t)$ of the data heads relative to their respective data tracks. A means must be provided for the measurement of the output. Assuming the system M to be controllable and observable, the position measurement method P must be capable of preserving both the controllability and observability of the system. The position $X(t)$ may be regarded as an information source operating at some capacity C_x. The information bandwidth of P must be sufficiently wide so as to provide enough information transmission as is required to ~~prevers~~ preserve controllability and observability. A similar requirement is laid upon the readback transducer channel T. P may be thought of as the "servo code" method employed while T models its implementation. P is constrained by the

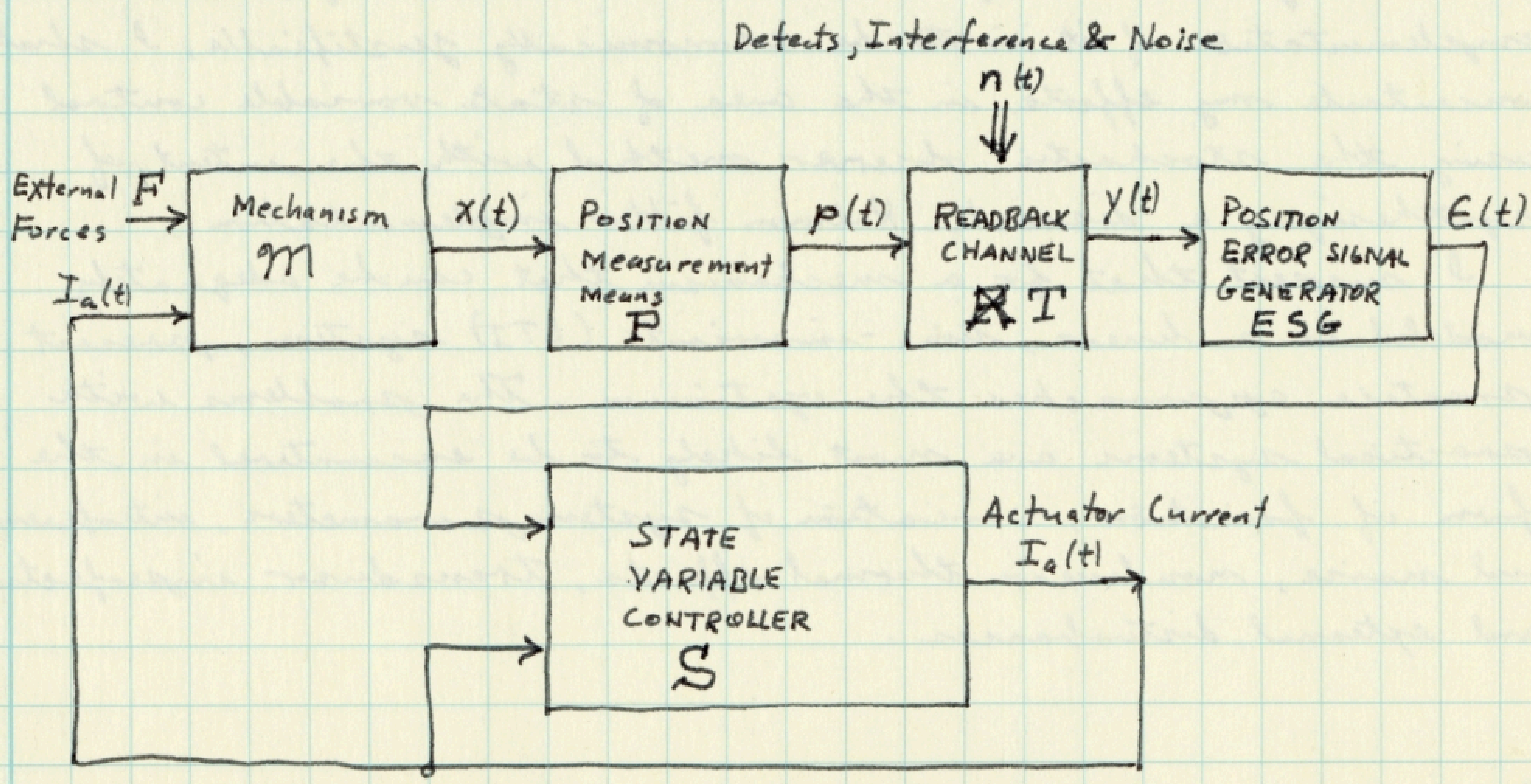

FIGURE 1

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canons of logic and mathematics while T is constrained by the physical nature of the transducer means employed. Normally, both P and T are under the control of the system designer within a given set of constraints. Technology will normally determine what properties of T are available. P will be principally constrained by information theoretic requirements and by cost requirements pertaining to the efficiency of media utilization. Inasmuch as the primary function of a disc memory is the storage of data, it is clearly desireable that the percentage of available storage given over to servo code information be minimized to as great an extent as is information-theoretically possible. System theoretic modeling of the cascaded system

$$\mathcal{D}_H = \mathcal{M} \,\square\, P \,\square\, T \qquad (1)$$

should make possible an information-theoretic analysis of the minimum requirements of P.

Given the measured output $Y(t)$, a means must next be provided for the generation of a position error signal. The ESG must be capable of providing measures of both track-following error ϵ_T and seek profile error ϵ_s.

If the cascade system

$$\mathcal{D}_0 = \mathcal{M} \,\square\, P \,\square\, T \,\square\, ESG \qquad (2)$$

is controllable and observable or, at the least, provides for output controllability and observability of subsystem $\mathcal{M}$, then a controller $\mathcal{S}$ may be realized by application of modern control theory techniques employing the state variable approach. By output controllability and output observability, it is meant that sufficient information is supplied to $\mathcal{S}$ by knowledge of $\epsilon(t)$ and $I_a(t)$ to permit control of the state of $\mathcal{M}$ by means of a stochastic observer technique.

The model of Figure 1 clearly indicates that the initial steps in developing a controller $\mathcal{S}$ is the system-theoretic modeling of the mechanism $\mathcal{M}$.

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A Simple Mechanism Model

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This entry will illustrate by means of a simple example the principles governing the behavior of electromechanical systems. The case to be considered is a simple linear voice coil actuator. The actuator is considered to consist of an assembly of rigid bodies. The carriage is assumed to be of mass M and is acted upon by viscous damping forces $b\,dX/dt$ and by a restraining force KX as well as friction and other forces $f_o(X,t)$. The actuator magnets ~~fro~~ produce a uniform magnetic field of density B. The voice coil is of total effective length l and carries actuator current $i(t)$. Figure 2 illustrates the mechanism assuming its motion is confined to the X-dimension.

An electrical model of the system is shown in figure 3. A source $e_s(t)$ with source impedance R_s drives the coil, which has resistance R_c (including any core losses). The coil inductance is composed of two terms. The leakage inductance, L_ℓ, accounts for that part of the induced magnetic field that does not cut the core of the return path. The magnetizing inductance L_m accounts for the effect of the steel return path. The current $i(t)$ is coupled to the mechanical system by the actuator magnet field B. The flux return path may also include a shorted turn which would reduce the total inductance $L = L_\ell + L_m$ by shorting out

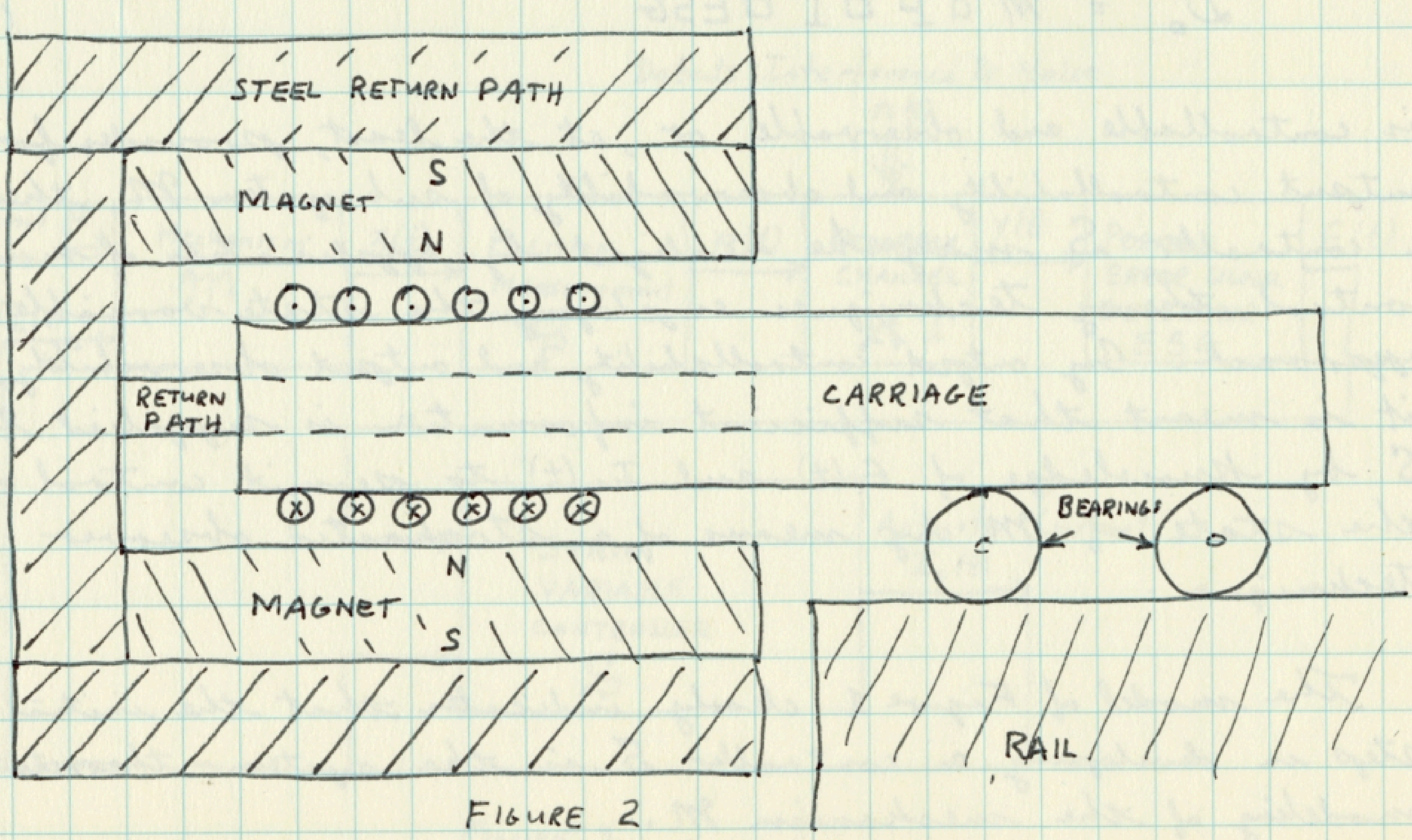

FIGURE 2

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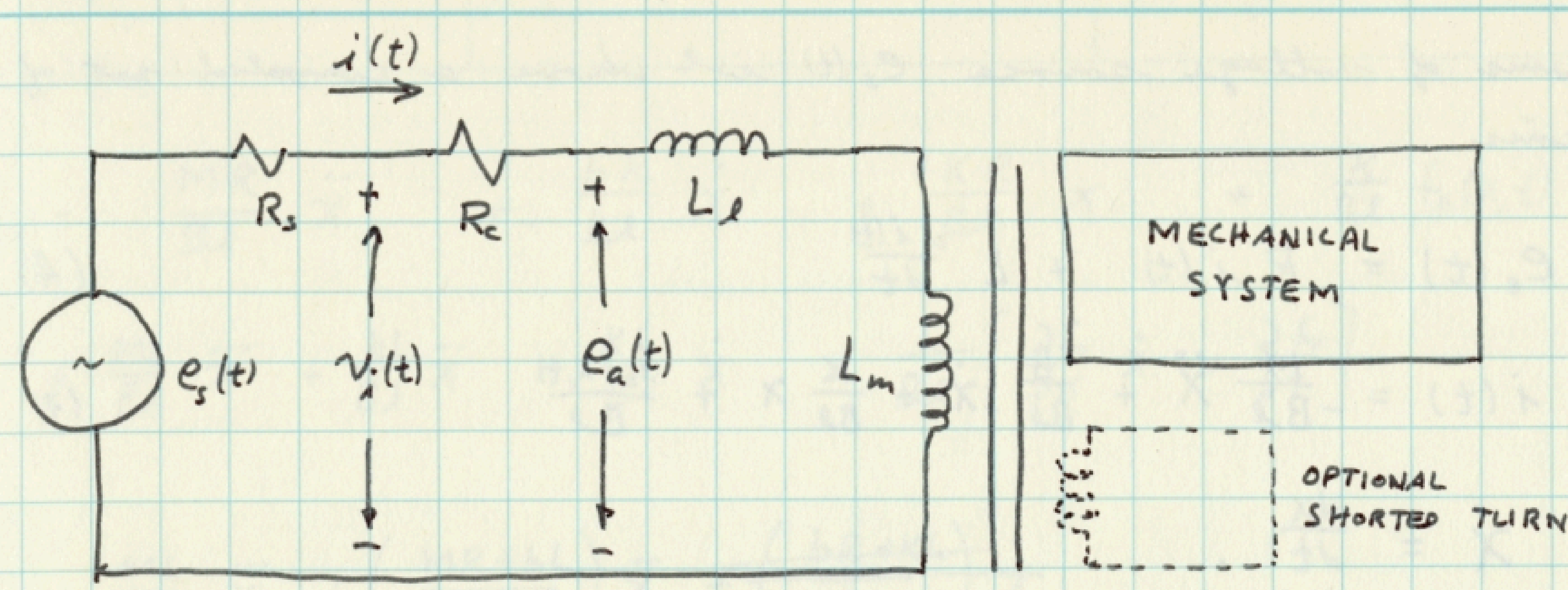

FIGURE 3

the magnetizing inductance via transformer coupling.

The total flux linkage in the system is $\phi = L i$. The back emf is given by

$$e_a(t) = \frac{d\phi}{dt} = L\frac{di}{dt} + i\frac{dL}{dt} = L\frac{di}{dt} + i\frac{dL}{dx}\frac{dx}{dt} \qquad (3).$$

where x is the position of the carriage. In a properly designed linear actuator, the coil moves in a region of uniform B field over the full travel range of the carriage. In this case, $dL/dx = 0$ and the loop equation of the system may be written

$$e_s(t) = R\,i(t) + L\frac{d\,i(t)}{dt} \qquad (4).$$

where $R = R_s + R_c$. The current $i(t)$ is coupled to the mechanical system as shown in figure 4. The force acting on the carriage due to the electromagnetic field may be written

$$f_{fld} = M\frac{d^2x}{dt^2} + b\frac{dx}{dt} + Kx + f_o(x,t) \qquad (5).$$

The ~~field~~ force f_{fld} is related to $i(t)$ by

$$f_{fld} = Bl\,i(t) \qquad (6).$$

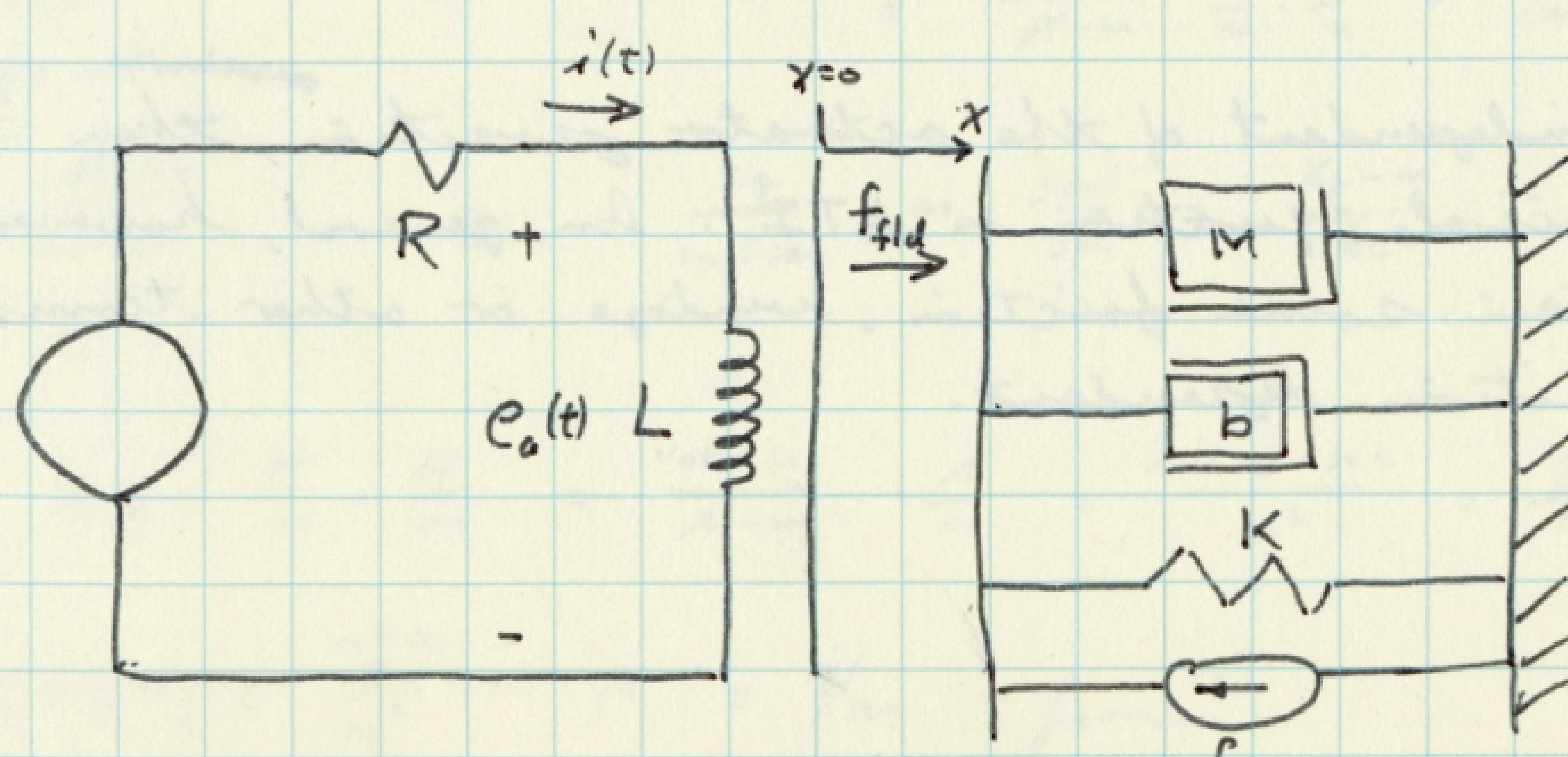

FIGURE 4

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