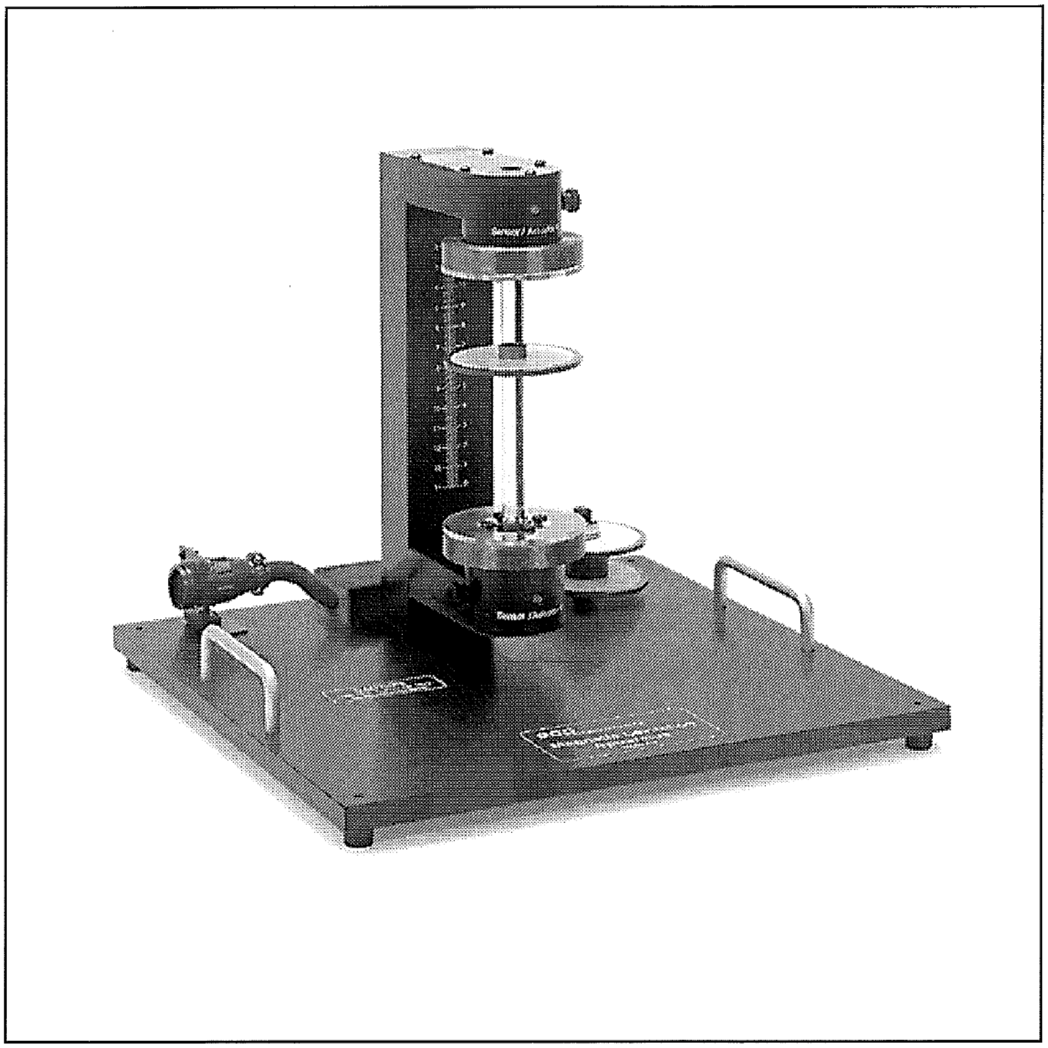
ENGR 6131

Project Description

Magnetic Levitation System



The Model 730 Magnetic Levitation Apparatus

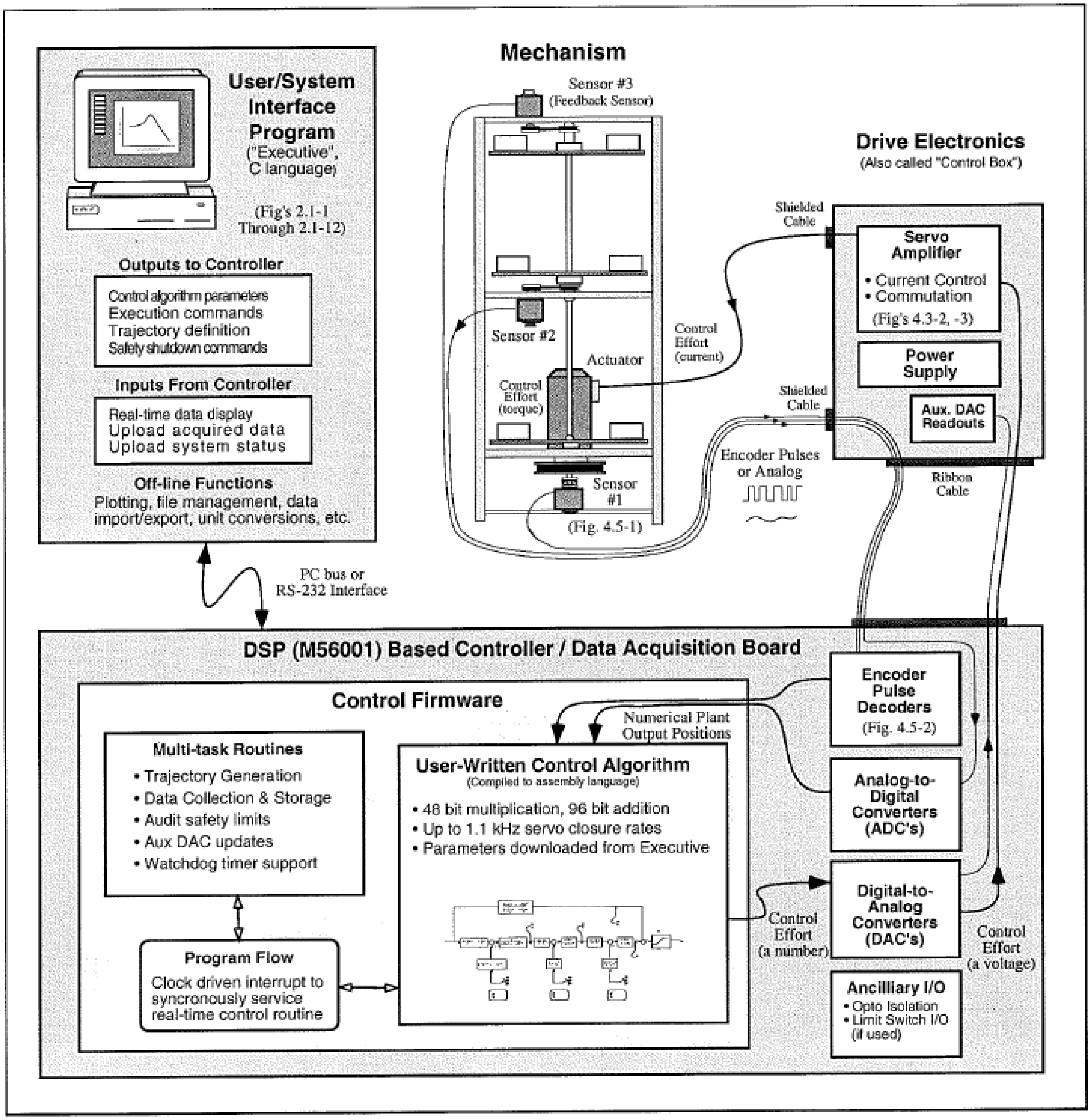


Figure 4.0-1. Overview of Real-time Control System.

This architecture is consistent with modern industrial control implementation.

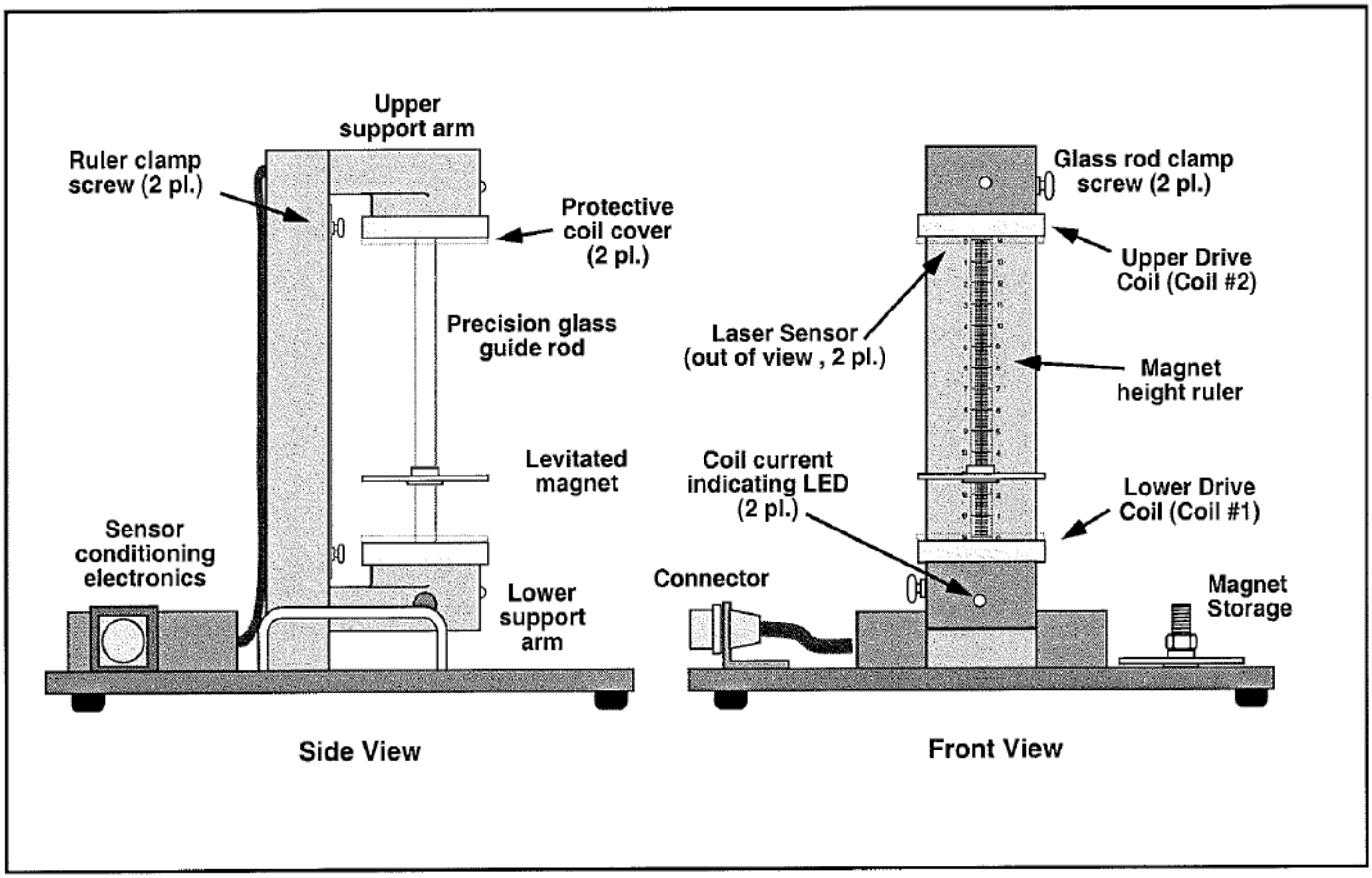


Figure 6.1-1. MagLev Apparatus

5. Plant Dynamic Models

This chapter provides time domain dynamical expressions in nonlinear and linear forms useful for control implementation and for use in the experiments described later in this manual. An overview of the principles of magnetism and magnetic levitation is given in Appendix A. The appendix gives the motivation for and form of the magnetic force terms used in this chapter.

5.1 Full Order Nonlinear Model

A free body diagram of two suspended magnets in the Model 730 apparatus is shown in Figure 5.1-1. Either magnet is acted on by forces from either drive coil, from the other magnet, from gravity, and from friction (modeled as viscous).

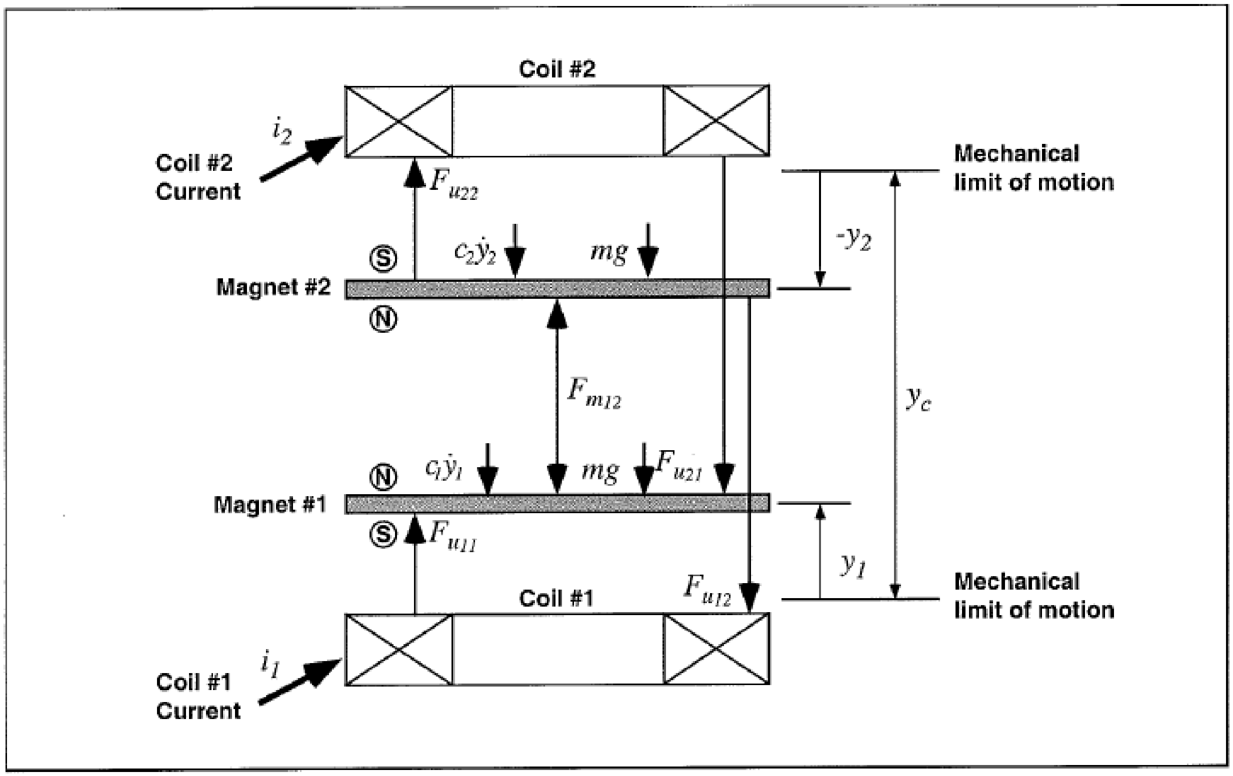


Figure 5.1-1. Free Body Diagram & Dynamic Configuration

From Figure 5.1-1, we have for the first magnet

$$m\ddot{y}_1 + c_1\dot{y}_1 + F_{m_{12}} = F_{u_{11}} - F_{u_{21}} - mg \tag{5.1-1}$$

Similarly for the second magnet

$$m\ddot{y}_2 + c_1\dot{y}_2 - F_{m_{12}} = F_{u_{22}} - F_{u_{12}} - mg \tag{5.1-2}$$

The magnetic force terms are modeled as having the following forms (see Appendix A for details)

$$F_{u_{11}} = \frac{i_1}{\boldsymbol{a}(y_1 + \boldsymbol{b})^N} \tag{5.1-3}$$

$$F_{u_{12}} = \frac{i_1}{\boldsymbol{a}(y_c + y_2 + \boldsymbol{b})^N} \tag{5.1-4}$$

$$F_{u_{21}} = \frac{i_2}{\boldsymbol{a}(y_c - y_1 + \boldsymbol{b})^N} \tag{5.1-5}$$

$$F_{u_{22}} = \frac{i_2}{\boldsymbol{a}(-y_2 + \boldsymbol{b})^N} \tag{5.1-6}$$

$$F_{m_{12}} = \frac{\boldsymbol{c}}{(y_{12} + \boldsymbol{d})^N} \tag{5.1-7}$$

where

$$y_{12} = y_c + y_2 - y_1 \tag{5.1-8}$$

and $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{c}$, $\boldsymbol{d}$, and N are constants which may be determined by numerical modeling of the magnetic configuration or by empirical methods. Typically $3<N<4.5$.

No details on Appendix A are provided or required!

5.2 Simplified Equations of Motion

The cross magnet/actuator forces, $F_{u_{12}}$ and $F_{u_{21}}$ are generally small compared to $F_{u_{11}}$ and $F_{u_{22}}$ for typical values of coil current and for the magnets in their normal operating range. For the Model 730 apparatus, the friction forces are also typically small. In addition, a value of four for the power of the denominator terms in Eq's (5.1-3 through -7) has been shown empirically to yield a

close approximation of the force/distance relationships – see Figure 5.2-1[1]. The following simplified model is therefore valid for many control design and analysis purposes.

$$m\ddot{y}_1 + F_{m_{12}} = F_{u_{11}} - mg \tag{5.2-1}$$

$$m\ddot{y}_2 - F_{m_{12}} = F_{u_{22}} - mg \tag{5.2-2}$$

where

$$F_{u_{11}} = \frac{u_1}{a(y_1+b)^4} \tag{5.2-3}$$

$$F_{u_{22}} = \frac{u_2}{a(-y_2+b)^4} \tag{5.2-4}$$

$$F_{m_{12}} = \frac{c}{(y_{12}+d)^4} \tag{5.2-5}$$

The parameters to be used for the above equations are as follows:

Operating conditions: y_1=2.00 cm, y_2=-2.00 cm, and y_c=12.00 cm.

The other model parameters are to be selected as: N=4, m=120 (g) , a=1.65, b=6.2, c=2.69, and d=4.2.

Project Tasks and Requirements

For the selected target application, you need to perform the following tasks.

Your final project report should address and provide in sufficient detail the following design and analysis issues, validation and verification through simulations. In preparation of your report, include the major parts of your work in the main body of the report, and present ALL the details in an Appendix detailing the derivations and the results. There are no page limits to your report. However, try to limit the main body of your report to less than 25 pages.

Make sure that your report is professionally prepared, that is it contains an Abstract, Introduction, Statement of the Problem, Design Specifications, Methodology, Analysis, and the Results and most importantly a Discussion section indicating the advantages and the disadvantages of your proposed design solution as well as a comparison between different design solutions and the rationale for selecting your best design solution from among many alternatives possible. The following is a list of the specific tasks that you need to investigate.

1. Starting with the input-output equations of the system, derive the state and output equations.
2. Find the transfer function of the open-loop system.
3. Obtain the controllable, observable, and Jordan canonical forms in Step (1).
4. Obtain the impulse response and the step response in Step (1) with arbitrary initial conditions.
5. Plot the Bode plot of the uncompensated system as well as the root-locus of the open-loop system.
6. Design a lead-lag or PID controller to meet certain design specifications (of your own choice). Try to include both transient as well as steady state characteristics.
7. Obtain the step response, square wave and sinusoidal responses
8. Plot the control input signal for each set point input in Step (7).
9. Examine the robustness of the design by introducing noise and parameter variations or uncertainty in the system.
10. Design a full state feedback control to meet the design specification indicated in Step (6).
11. Obtain the step, square wave and sinusoidal responses with arbitrary initial conditions and compare the results with those in Step (7).
12. Plot the control input signal for each set point input in Step (11) and compare the result with those in Step (8).
13. Design a full-order and a reduced-order observer and obtain step and sinusoidal responses.
14. Find the transfer function of the observer and controller. What type of controller do you get?
15. Provide a comparative study between the classical control design advantages and disadvantages with that of modern control theory design.
16. Provide justifications for your comparative study through numerical simulations.