The system, shown in Figure 1, uses a beam of electrons to generate patterns on the master “masks” from which integrated circuits are made. The mask rests on a stage which moves in the x-y plane. This stage is to be suspended using four magnetic suspensions located at the corners of the stage. The whole system will operate in a vacuum at about 14 degrees Kelvin to avoid dispersion of the beam. We shall examine only one magnetic station as depicted in Figure 2. The immediate objective is to investigate the dynamics of and controls involved in maintaining the vertical displacement $z$ of the stage.
1. Explain why the designer considered the use of a magnetic system for suspending and moving the stage rather than a hydraulic system?

2. Given the block diagram of the suspension in Figure 3, find the transfer function \( \frac{z(s)}{V(s)} \).

   (Assume \( f_d = 0 \))

3. Give an intuitive physical reason explaining the stability characteristics of this suspension.

4. Assuming \( G_f = 1 \) and the effects due to the coil driver dynamics are negligible, discuss the merits of the following controllers:
   a. Proportional
   b. Proportional – Derivative
   c. Proportional – Integral – Derivative

5. In this application the vertical displacement \( z \) must be controlled accurately despite the unpredictable disturbance \( f_d \). Assuming that \( G_f = 1 \), discuss the dynamic behavior of the compliance (inverse stiffness) for this suspension for controllers (ii) and (iii) of part (3).