is the critical damping coefficient, and

$$\omega_n = \sqrt{\frac{k}{M}}$$

is the natural frequency.

Comparing Equation (4.13) to Equation (4.2), we see that they are of the same form and so the steady state component of the solution can immediately be written as

$$x(t) = X \sin(\omega t - \phi),$$ \hspace{1cm} (4.14)

where

$$X = \frac{me \zeta^2}{M \sqrt{(1 - r^2)^2 + (2\zeta r)^2}}$$ \hspace{1cm} (4.15)

and where the phase angle is unchanged and is given by Equation (4.6)

$$\tan \phi = \frac{2\zeta r}{1 - r^2}.$$

Thus, the frequency response function for this system is the same as that depicted in Figure 4.2(a), except that \( Z \) is replaced by \( X \) and \( Y \) is replaced by \( \frac{me}{M} \).

### 4.3 System Constants and General Hints for the Laboratory Experiment

The following list provides physical data associated with the laboratory experiment. Also, because the system you are going to use can have extremely low damping (close to zero), transient solutions can last for a great deal of time. Sometimes there is a need to wait for these transients to decay so that a steady state amplitude can be observed. One way to speed-up this process is to increase the damping, thus causing the transient to decay faster. The damping can then be slowly reduced again. In general, it is good to change parameter values (speed, damping) slowly and to carefully watch the resulting trends as you make the changes. This way, transient behavior does not get introduced. Do these trends agree with, for example, the plots shown in Figure 4.2?

One final point. The control labeled Base Motion Frequency is a multi turn potentiometer that controls the frequency of the base motion by changing the
speed of the motor on the far left of the test apparatus. The potentiometer turns a total of ten times. The zero speed (frequency) is preset to be in the center of this range, i.e., 5 turns from the fully counterclockwise or clockwise position. Hence, to obtain a zero frequency, turn the control either fully left or right and then turn it back 5 turns. The frequency of the base motion can now be increased by turning the control in either direction.

Physical Parameters

(a) The total mass of the system, including the unbalanced mass, $M = 2.64$ kg.

(b) The total spring stiffness, $k = 54 \, N/m$.

(c) The damping coefficient, $c$, is proportional to the current in the electromagnets. A plot for converting the current (Amps) to $c \, (Ns/m)$ is provided in the laboratory. Take care to note that $\zeta = \frac{c}{2\sqrt{kM}}$.

(d) The LVDTs (the displacement transducers) have been calibrated to 1 Volt/cm.

(e) The amplitude of the frame motion has been fixed to give $Y = 0.25 \, cm$. 