The Use of an Electronic Classroom in Teaching an Undergraduate Vibrations Course

W.L. Cleghorn
University of Toronto

Abstract
This paper describes some results of recent efforts made to employ electronic classrooms in teaching engineering courses in the Faculty of Applied Science and Engineering, University of Toronto. Particular emphasis has been placed on adopting updated methods in teaching an undergraduate course on vibrations, in the Department of Mechanical and Industrial Engineering. Some examples of computer animations and physical demonstration models used are presented.

1. Introduction

Over the past two years, several large classrooms at the Faculty of Applied Science and Engineering, University of Toronto were upgraded through installation of electronic capabilities. This has allowed teaching techniques to be expanded and improved. For instance, in the past year, the author used these facilities in teaching an undergraduate vibrations course to a class of more than 100 students.

This paper describes the material prepared for the vibrations course, using the electronic classrooms, including:

- a series of computer animations to illustrate various important aspects of vibration phenomena, based on a computer software package entitled Working ***Model',*** which enables animations to be shown through use of a video projector
- a series of physical models, which can be effectively shown during lectures using a video document camera.

2. Overview of Electronic Classrooms

There are five electronic classrooms within the Faculty of Applied Science and Engineering. These rooms have seating capacities ranging from 80 to more than 250. The electronic equipment installed in each room was standardized to ensure that instructors could easily use any of them, with minimal special training for each room. Each room is now equipped with a remote controlled video projector suspended from the ceiling. In addition, the following items are readily accessible to the instructor at the front of the class:

- video cassette tape player
- video document camera
- output connectors for signals from external sources, for computer graphics (VGA or Macintosh) and video (NTSC or super VHS)

- Ethernet connection (connection to other computers on campus or the Internet)
- touch controls for the power projection screen, 35mm slide projector, and lighting

All of these items are housed in a cabinet with a combination access lock for security purposes. All instructors have their own combination which can be used for access to the equipment in all of the electronic classrooms.

Combination access is not necessary for using the lecture room when the electronic capabilities are not needed. Redundant controls for the power projection screen and lighting are wall mounted, outside the cabinet.

3. Computer Animations Using *Working Model* Software

A series of animations was produced using the computer software package entitled ***Working Model.*** This software is ideally suited for illustrating several critical areas in a vibrations course where detailed discussion and explanation are needed. Some typical animations are described in this section.

Presentation of these animations allowed students to gain a fuller understanding of the material presented. In preparation for presenting the animations, students were provided with a hard copy prior to starting the lecture. This gives students have the option of reviewing the animations on their own, after lectures, since all animations developed are stored in the undergraduate PC laboratory. Students may also try out variations of what they saw during lectures by varying the values of the parameters. Incidentally, a laser pointer proved to be very useful in explaining animations in class.

3.1 Free Vibration of a Damped One Degree of Freedom System

Figure 1 shows the set up used to illustrate free vibration of a damped system having one degree of freedom. The three systems illustrated have the same mass and stiffness. However, the amount of damping in the three systems is varied. Figures l(a), l(b) and l(c) show under damped, critically damped and over damped conditions, respectively.

In this demonstration, all systems are initially displaced an equal distance from the equilibrium position and released. Markers on the trace paths move in coordination with the motion of the masses.

3.2 Forced Vibration of a Damped One Degree of Freedom System

Figure 2 shows the set up used to illustrate the response of a damped system having one degree of freedom subjected to a harmonic force. Each of the systems has identical mass, damping and stiffness. All are subjected to a harmonic force of the same magnitude. The only difference between systems is the frequency of the harmonic force. For Figure 2(a), the forced frequency is less than the undamped natural frequency; Figure 2(b) is forced at resonance (that is, the forcing frequency equals the undamped natural frequency); Figure 2(c), the forced frequency is higher than the undamped natural frequency.

Displaying these three systems side by side makes it easy to compare several aspects. For instance, the phase angle between the applied force and the resulting motion can be easily examined. Figure 2(a) has a phase angle which is essentially zero; Figure 2(b) has a 90 degree phase angle; Figure 2(c) has a phase angle which is close to 180 degrees.

Also of interest is the change in the steady state amplitude of motion relative to the applied frequency, after the steady state motions have died out. At the condition of resonance, for instance, the amplitude of the response is larger than for the other cases considered. However, it does not increase to infinity in theory or in practice due to the presence of damping.

3.3 **Base Excitation of a One Degree of Freedom System**

Figure 3 shows three identical systems, all subjected to a base motion of the same amplitude. However, the frequency of base motion is below, equal to and above resonance for Figures 3(a), 3(b) and 3(c), respectively. In this demonstration, a visual comparison can readily be made between the magnification factor of the motion of the mass, relative to the motion of the base, as well as the phase angle of the motions. These comparisons are similar to those for the study of forced vibration.

3.4 Normal Mode Vibration of a Multiple Degree of Freedom System

Through the application of the *Working Model* software, it is possible to develop models having multiple degrees of freedom, and to study their normal modes of vibration. Figure 4(a) illustrates the two normal modes of the two degree of freedom system. The linear translation of the centre of mass and rotation of the body are shown in separate diagrams. In each diagram, the initial conditions are such that the system will vibrate in one normal mode. If the system has initial conditions other than those given in Figure 4(a), as shown for instance in Figure 4(b), the motion is not a normal mode vibration. For this condition, there may be a beating motion, as shown for the rotation shown in Figure 4(b).

3.5 Tuned Vibration Absorber

Figure 5(a) illustrates a pronounced response in a system which is forced near its undamped natural frequency. Figure 5(b) shows the same system, to which a vibration absorber has been added and tuned to the forcing frequency. It illustrates a dramatic reduction in the amplitude of the main mass of the system. In this system it is necessary to include a small amount of damping so that the response decays to a steady state, and the transient solution dies out. For the model illustrated, the damping was selected to be approximately one percent of critical damping.

4. **Physical Models**

A series of physical models were used for illustration during lectures. They were shown effectively using the in-class video document camera, including:

- a device for measuring polar mass moment of inertia through using a torsional vibrating system
- a slider crank mechanism mounted on a flexible support

- a one degree of freedom system having free vibration with variable mass, damping and stiffness to demonstrate under damped and over damped responses

- one-plane balancing machine

Only the one-plane balancing setup is illustrated in this paper (Figure 6). This model was modified from a unit originally purchased from *Didactec* Engineering *Equipment*[2] to now include a disc which was designed to accommodate application of plasticine to act as trial and balancing masses. Through the use of a strobe light (not shown in the Figure), it was possible to illustrate the effects of changing the magnitudes and locations of the amplitude and the phase angle of the resultant vibration.

5. Summary

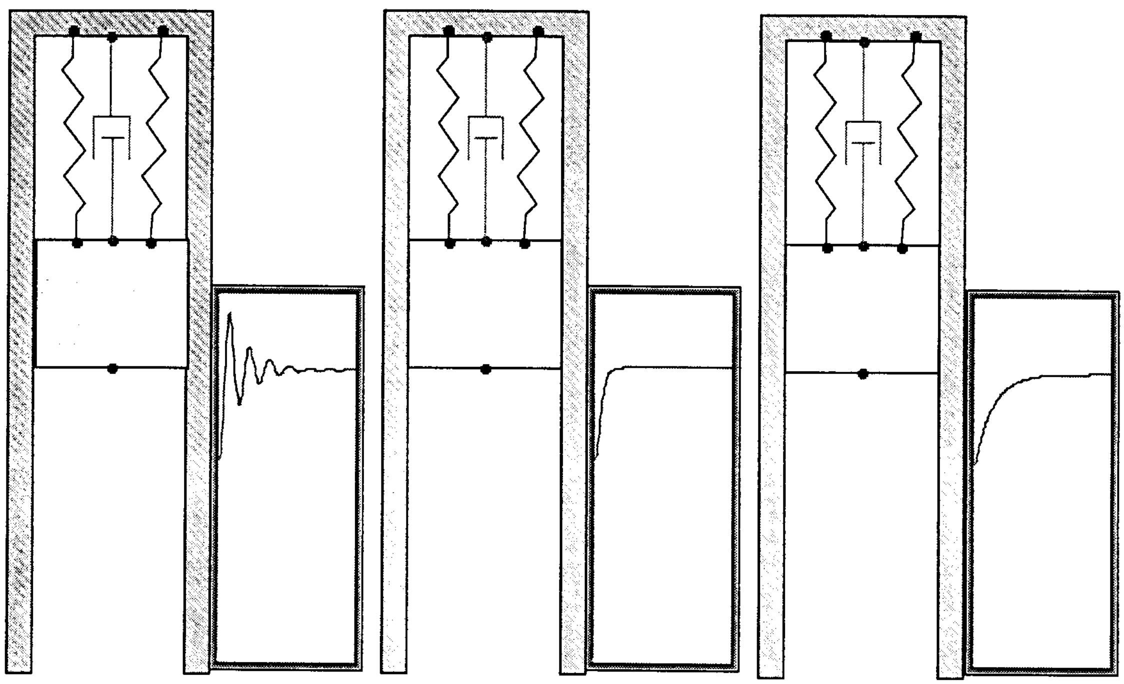
This paper has described the use of electronic classrooms in undergraduate teaching at the University of Toronto. Response from students on the use of these demonstrations were complimentary and positive. The use of electronic classrooms is becoming more prevalent and demand of the electronically equipped classrooms is increasing.

Bibliographic Information

1. Working *Model* User's Manual, Knowledge Revolution, San Mateo, CA 1995.
2. *Didactec Engineering Equipment* Operator's Manual for Simple Balancing Apparatus.

Biographical Information

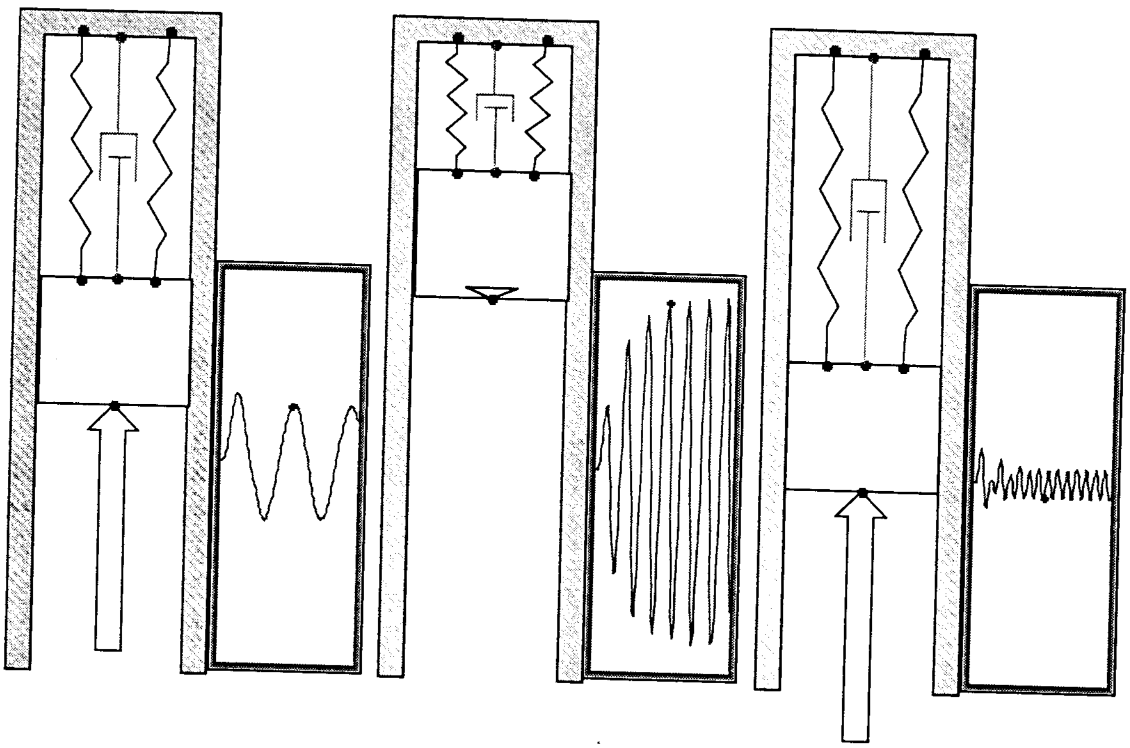
WILLIAM L. CLEGHORN completed his Ph.D. in 1980 at the University of Toronto in the field of kinetoelastodynamics. Since then, he has worked in the pulp and paper industry and at the University of Manitoba, Department of Mechanical Engineeriring. In 1986, he joined the Department of Mechanical and Industrial Engineering, University of Toronto, and is currently a Professor in the Department.



(a) (b) (c)

Figure 1 **Free Vibration of a Damped One Degree of Freedom System**

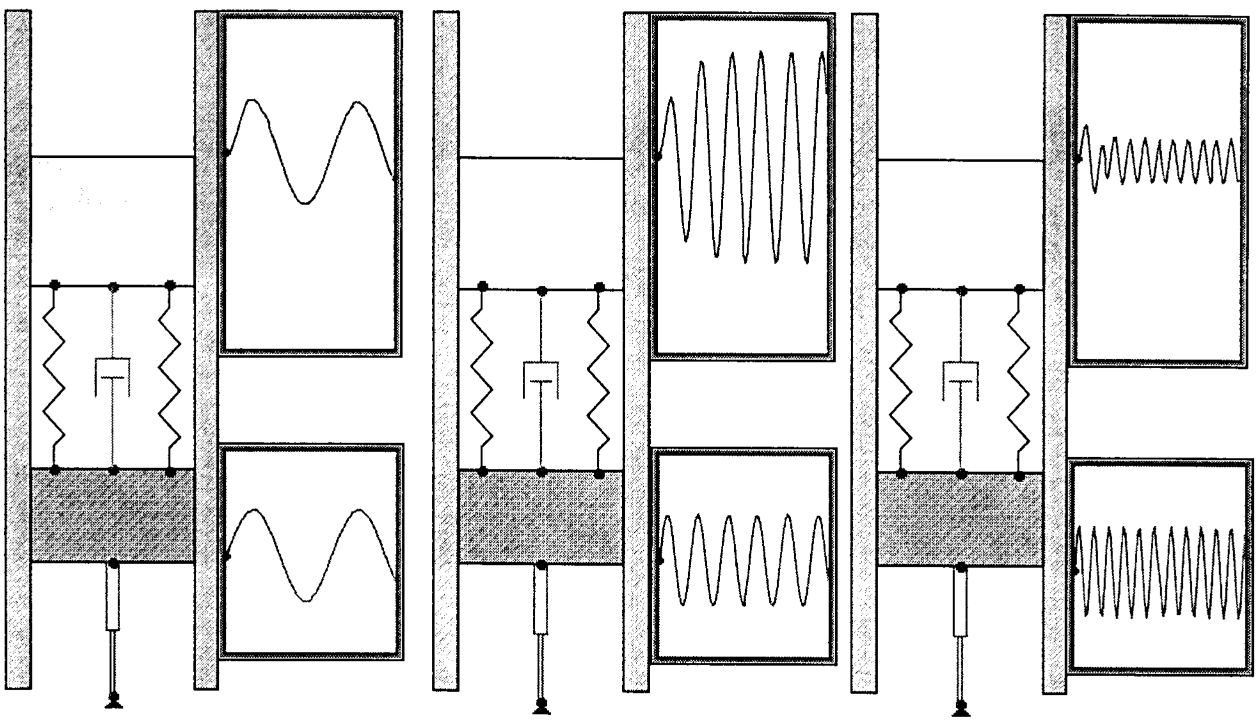
(a) Under Damped
(b) Critically Damped
(c) Over Damped



(a) (b) (c)

Figure 2 **Forced Vibration of a Damped One Degree of Freedom System**

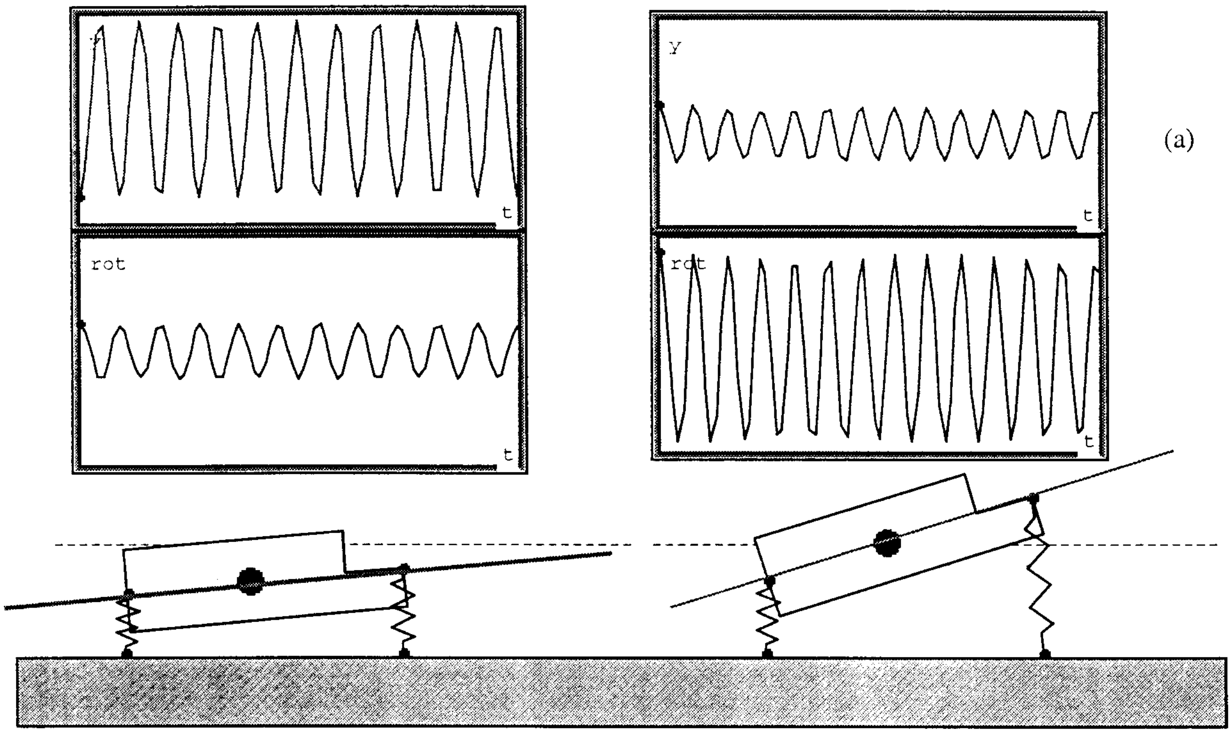
(a) Forced Frequency less than Natural Frequency
(b) Forced Frequency equal to Natural Frequency
(c) Forced Frequency greater than Natural Frequency



(a) (b) (c)

Figure 3 **Base Excitation of a One Degree of Freedom System**

(a) Base Excitation Frequency less than Natural Frequency
(b) Base Excitation Frequency equal to Natural Frequency
(c) Base Excitation Frequency greater than Natural Frequency



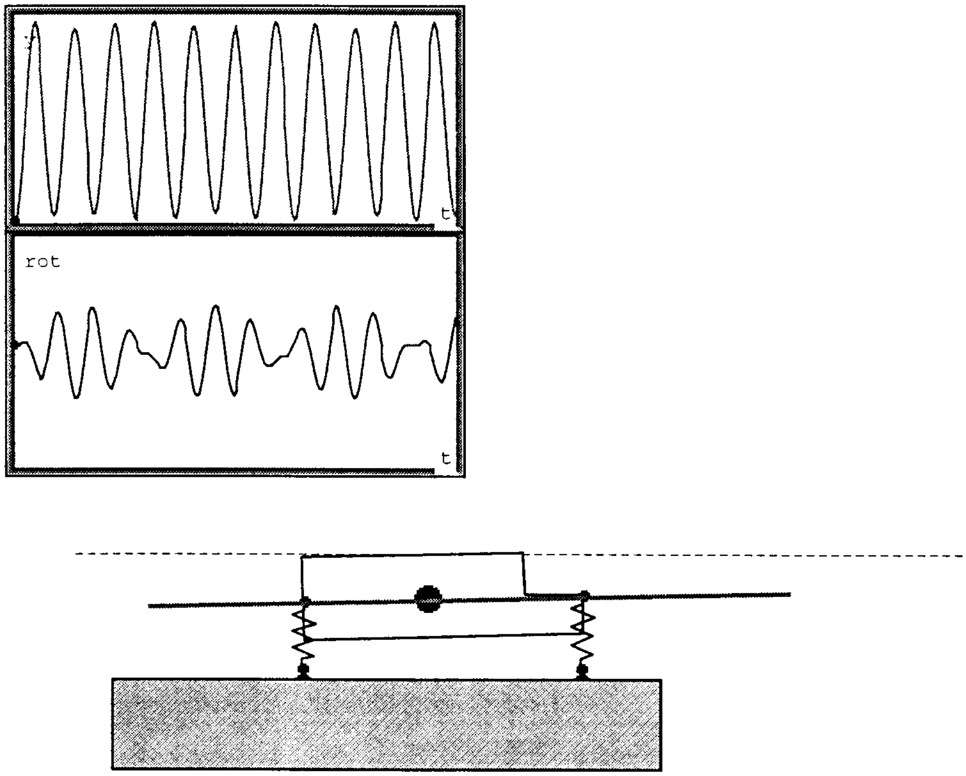
(a)

First Normal Mode

Second Normal Mode

Figure 4 **Vibration of a Two Degree of Freedom System**
Page 1 of 2 pages

(a) Normal Mode Vibrations



(b)

Figure 4 **Vibration of a Two Degree of Freedom System**
Page 2 of 2 pages

(b) Arbitrary Initial Conditions

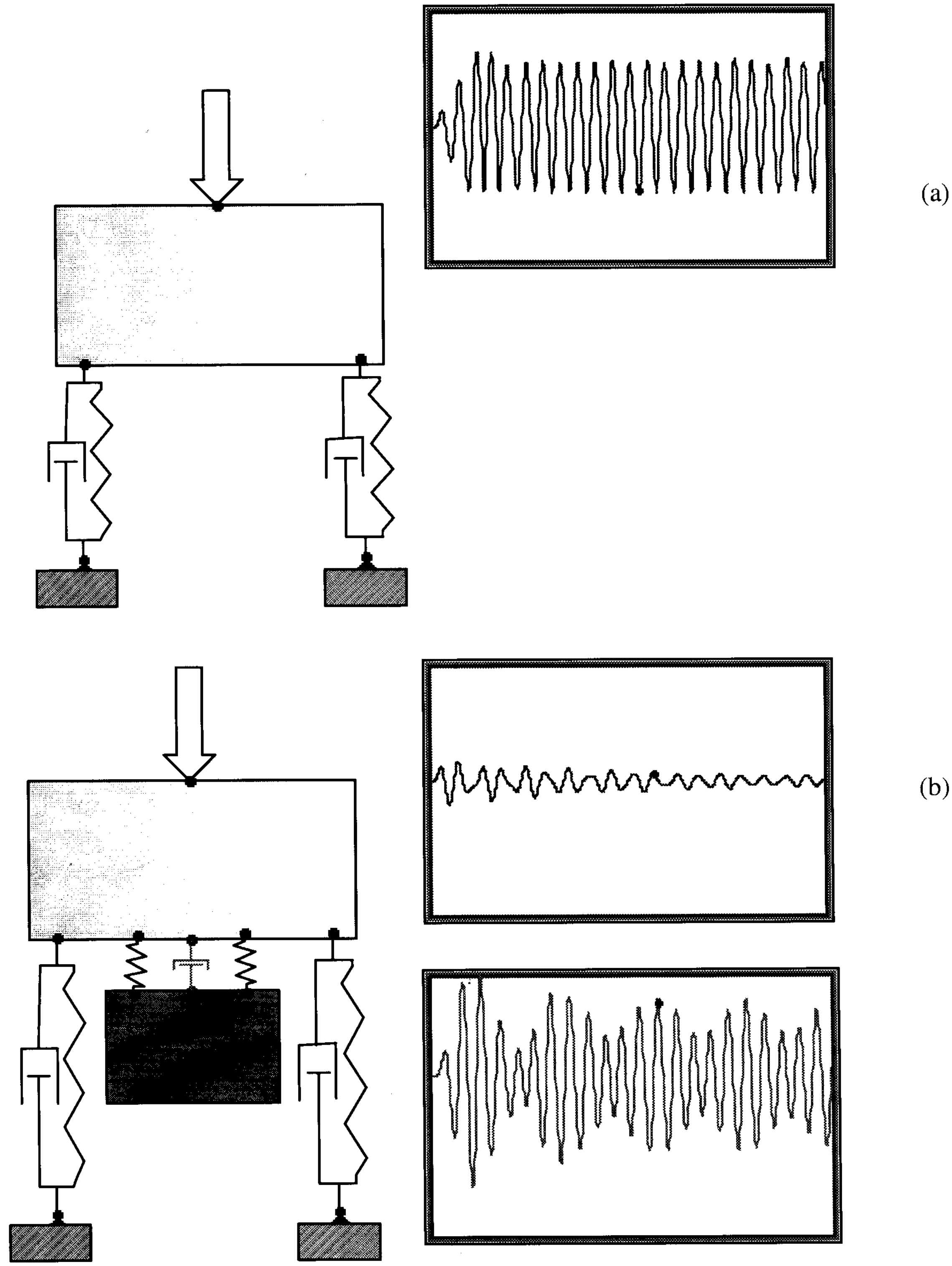


Figure 5 **Tuned Vibration Absorber**

(a) No Absorber Mass
(b) Absorber Mass Added

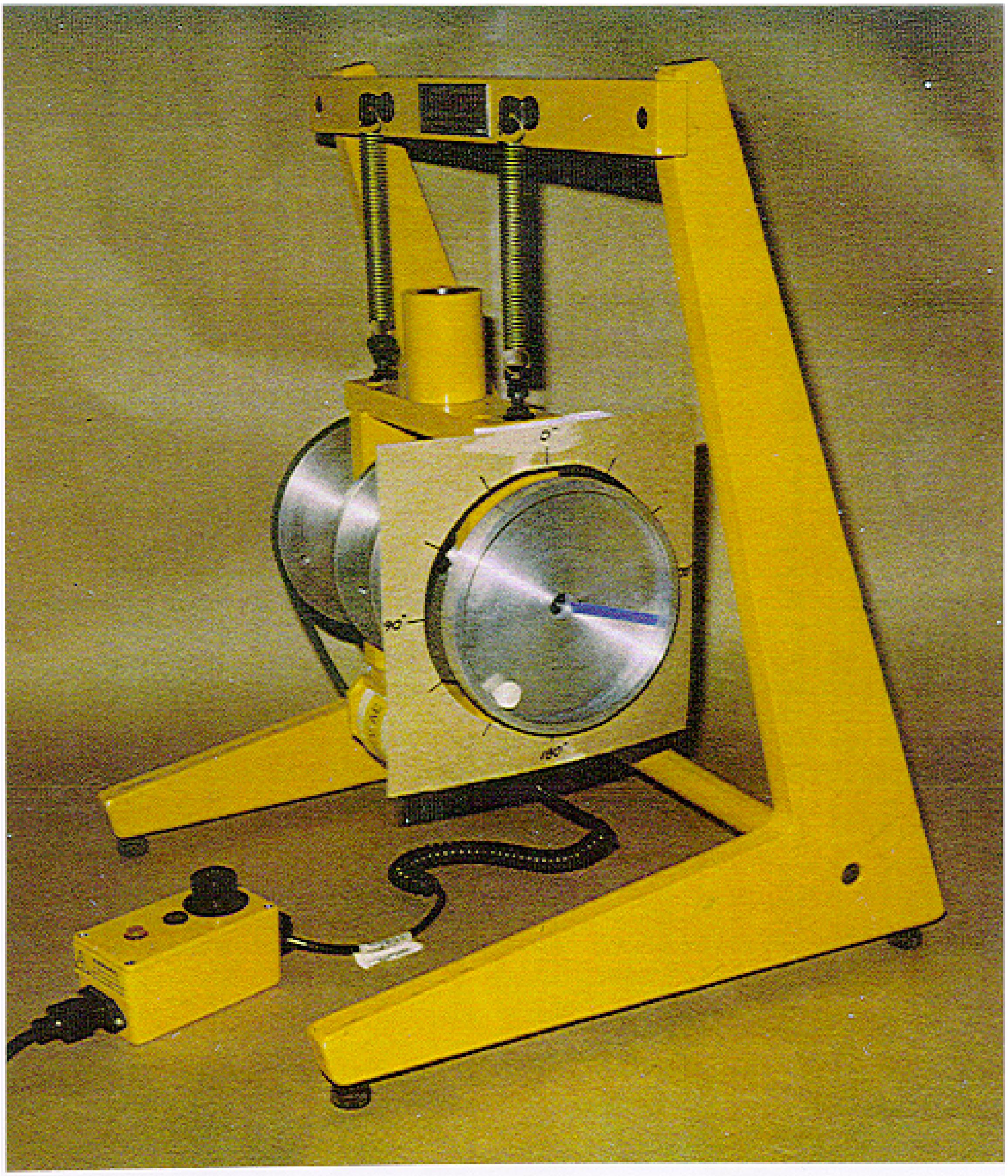


Figure 6 One-Plane Balancing Setup