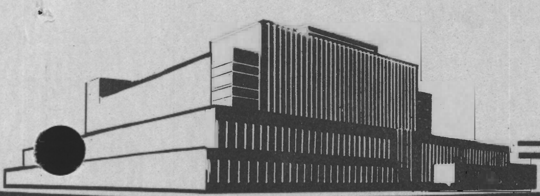
(Report) 2239

THE FPL LINEAR DEADWEIGHT ACCELEROMETER CALIBRATOR

February 1962

No. 2239



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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE FPL LINEAR DEADWEIGHT ACCELEROMETER CALIBRATOR

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Summary

An accelerometer calibrator that provides a convenient and satisfactory method of checking the response characteristics of accelerometers on an operational basis was constructed at the Forest Products Laboratory. The calibration can be made under normal operating conditions of the accelerometer.

Introduction

A device for the calibration of linear accelerometers was recently constructed at the Forest Products Laboratory.

At the Laboratory such accelerometers are used to measure dynamic force or acceleration during research on the properties of packaging materials. Strain-gage accelerometers are used with this calibrator, but any type of linear accelerometer may be calibrated with the device.

The linear deadweight accelerometer calibrator is based on an article by Pinsky.[2] The basic theory given in the article has been used, but modifications have been made in the calibrator, and operating techniques have been developed.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Pinsky, Herman. Linear Dead-Weight Accelerometer Calibration. Instruments and Control Systems, July 1961.

Theory of Operation

The theory of the calibrator is based on Newton's Second Law of Motion, $F = ma$. The accelerometer is suspended in a static system of balanced forces as shown in figure 1. The values of forces F_1, F_2, and F_3 and the value of the mass of the accelerometer may be obtained by measurement. When one of the forces is suddenly removed, the vector sum of the remaining forces produces an acceleration that may be determined from the known quantities.

The accelerometer is mounted so that its sensitive axis is in the horizontal plane. Forces F_1 and F_2 that are shown in figure 1 cannot act precisely in a horizontal plane because of the action of force F_3, which is produced by the weight of the accelerometer. However, F_3 will always be much smaller than F_1 and F_2, and the resultant horizontal component of force F_1, ($F_1 \cos \theta$), will be nearly equal to F_1 if the angle θ is small. For example, when θ is 8°, the horizontal component of F_1 will be greater than 99 percent of F_1, and the effects of F_3 may be neglected.

Force F_1 is applied by an elastic body (fig. 2). The magnitude of this force is determined by the weight (W_1) that stretches the elastic body. A change of direction of the force is attained by a freely rotating pulley. The elastic body works within its elastic limit, and serves to provide an essentially constant force for a finite period of time when the force system is unbalanced.

Force F_1 and the mass of the accelerometer (m) are accurately determined by weighing. When the force system is suddenly unbalanced by releasing force F_2, the resulting acceleration (a) may be calculated as follows:

$$F_1 = W_1 = ma$$

$$a = \frac{W_1}{m}$$

where

$$m = \frac{\text{Weight of accelerometer}}{\text{Acceleration of gravity}} = \frac{w}{g}$$

$$a = \frac{W_1}{m} = \frac{W_1 g}{w}$$

$$G = \frac{\text{Acceleration}}{\text{Acceleration of gravity}}$$

$$G = \frac{a}{g} = \left(\frac{W_1 g}{w}\right)\left(\frac{1}{g}\right) = \frac{W_1}{w}$$

The resulting acceleration in units of gravity (G) equals the ratio of the weight that produces the propelling force to the weight of the propelled object.

Thus, a known step-function of acceleration may be applied to an accelerometer, and the resulting output signal may be recorded by a suitable recording device.

Design Considerations

The FPL calibrator is designed to produce accelerations of up to 250 G with accelerometers that weigh 0.25 pound, and with tensional forces of up to 90 pounds. Since the acceleration that can be obtained is inversely proportional to the weight of the accelerometer, higher accelerations can be obtained with lighter instruments, and correspondingly lower maximum values for acceleration will be produced with heavier accelerometers.

The spring length of 12 to 15 inches that has been used is a compromise between using a long spring to obtain an essentially constant force and making the calibrator small enough to be portable.

Construction

The calibrator (fig. 3) that was constructed at the Forests Products Laboratory is mounted on a mobile cart so that it may be conveniently used at any test location. Since the calibrator is long and narrow, the cart is constructed so that the calibrator occupies one side, and the remaining width is available as a work surface. Storage space is provided in the cart, and a hinged cover protects the calibrator when it is not in actual use. Adjustable brackets are mounted in slotted tracks on the cart top so that accelerometers of differing types and sizes may be calibrated. A small winch is provided for ease in handling the weights.

A 3-inch ball bearing, aircraft-type pulley is used to suspend the weights. All interconnecting cable is as light as possible, consistent with strength requirements. Stranded galvanized aircraft control cable of 1/32-inch diameter is used.

A set of graduated weights (fig. 4) permits any desired force up to 85 pounds to be obtained. A small shot container is used to obtain the exact weight desired. A hole that was cut in the bottom of the cart allows free passage of the weights. This permits a greater range of extension of the spring without making the cart unwieldy in size.

The calibrator itself consists of a number of components that are shown in figure 5. The release mechanism (1) is designed to carry the maximum force that is imposed on the calibrator without slippage or the danger of accidental release, and is capable of releasing the force rapidly and smoothly. Pressure-type clamps were tried, but were found to be unreliable and unable to restrain the maximum forces desired. The method adopted uses a hardened steel pin that projects through a perforated metal tab. This pin provides positive restraining action. When the release knob is depressed, the pin is withdrawn, giving a very rapid and smooth release. A snap-action switch (2) is mounted under the release mechanism so that a triggering signal may be supplied to the recording device used. The switch position is adjustable so that the time relation of the triggering signal to the leading edge of the calibration pulse may be adjusted.

The accelerometer (4) is mounted on a bracket and harness (3) which maintains it in the proper attitude and permits connection to the balanced force system. The bracket is designed to be as stiff and as light as possible. A section of light alloy box strut is used as the bracket for the accelerometer shown in figure 4. Different types of accelerometers will require different mounting brackets.

A cushion (5) is provided so that the accelerometer will not be damaged by excessive deceleration. The cushion used on the FPL calibrator is composed of three 1-inch layers of materials with varying densities to provide satisfactory cushioning at all levels of input acceleration. The front layer is synthetic rubber with a density of 15.0 pounds per cubic foot. The middle layer is urethane foam, polyether type, with a density of 1.5 pounds per cubic foot, and the third layer is the same material, with the density further reduced by 3/4-inch holes punched throughout the cushion. The layers of the cushion are glued together and mounted on a 1/2-inch plywood backing that is attached to an adjustable metal support bracket (6). This combination of layers provides deceleration levels that remain less than input accelerations over the entire range of the calibrator. This assures that any accelerometer that is tested will not be damaged by unintentional overloads. Any other suitable cushion might be used that would provide sufficient protection for the accelerometers. A 1-inch hole through the entire cushion assembly allows the suspension cable to pass through without making contact.

A helical wire tension spring (7) is used as the elastic body that provides the operating force. The FPL calibrator is designed to use springs that are approximately 12 to 15 inches long in the unloaded state, and that may be stretched to over twice their original length without permanent deformation. Since any one spring can produce only a limited range of force values near the desired condition of double extension, a number of different springs are necessary to cover the entire range of the calibrator. Screen door closing springs are satisfactory for the lower force ranges and are commonly available in several degrees of stiffness. Accelerations of up to 120 G can be obtained with springs of this type. It was necessary to obtain a stiffer spring with a spring constant of 6 pounds per inch to reach the upper design limit of 250 G.

A bracket (8) was installed to restrain spring movement, primarily for safety purposes, after approximately 1 inch of free travel. An unrestrained spring that operates with forces of up to 85 pounds could constitute a serious hazard if released unintentionally or unexpectedly. The spring passes through a hole in the bracket, and a steel rod that is fitted with rubber snubbers is passed through the loop in the end of the spring (9). The restraining bracket may be adjusted so that any desired amount of free travel may be obtained. The snubber rod engages the bracket and prevents further motion of the spring. This rod also removes the propelling force from the accelerometer, and helps prevent damage to the accelerometer during deceleration. The positions of the brackets are adjusted so that the propelling force is removed before the accelerometer contacts the cushion.

Operation

To obtain the greatest possible accuracy, a number of operational precautions should be taken. The cart should be blocked and leveled so that no reaction movement is possible and so that the accelerometer may be positioned with its sensitive axis in the horizontal plane. The triggering switch is connected in series with a suitable triggering voltage and fed to the external trigger input of the oscilloscope that is used to record the output of the accelerometer. The position of the trigger switch and the sweep rate of the oscilloscope are adjusted so that a reference base line is obtained both before and after the calibration pulse. A sweep rate of 2 milliseconds per centimeter has been found most satisfactory.

When the weight that is needed to produce a desired acceleration is calculated, the accelerometer, its mounting bracket, and all of the harness between the spring and the restraining pin must be considered as the accelerated mass. This weight must be determined accurately because weighing is the most probable source of error in the calibration procedure. The stiffness of the accelerometer cable will influence the weighing, and the cable should be positioned carefully so that it does not exert a force, and so that the weight of about 4 inches of the cable is included in the total weight. When the accelerometer is suspended in the balanced force system, the cable must be positioned so that it can move freely with the accelerometer without exerting an opposing force. The release mechanism should be operated slowly and smoothly to avoid setting up vibrations in the balanced force system. If the release mechanism is working properly, a rise time of 1/2 millisecond or less will be obtained. No part of the balanced force system should contact the brackets as it passes through the holes.

The spring snubbing bracket should be adjusted so that the time duration of the applied acceleration is always at least five times as long as the natural period of the accelerometer being calibrated. If this is observed, the accelerometer should reproduce the input pulse most accurately as shown by Levy and Kroll.[3]

Interpretation of Data

The idealized step function of acceleration that is produced by a linear spring is shown in figure 6a. Acceleration rises instantaneously to a peak value. As displacement of the free end of the spring occurs, the propelling force decreases linearly to zero, and the value of acceleration changes accordingly. A long spring operated at the greatest permissible extension within its elastic limit will have a low rate of change of force per unit of time and the acceleration that is produced will decrease at a slow rate from its peak initial value. The exact value of force is known only at the instant of release, so this is the instant when the calibration is determined.

In an actual operating system, the acceleration does not rise instantaneously, but takes a finite length of time to rise to the maximum value as shown in figure 6b because of friction and movement in the release mechanism. During this time the value of the force has decreased by some very small amount. Correction for this change can be made as shown in figure 6b by extending the slope of the top of the pulse to intercept a vertical line at the instant of release. In this discussion, the assumption is made that the associated electronic equipment does not cause detectable deterioration of the input signal. The rise time of the oscilloscope used at the Forest Products Laboratory is 0.18 microsecond.

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[3] Levy, S., and Kroll, W. D. Response of Accelerometers to Transient Accelerations, Research Paper 2138, National Bureau of Standards Research Journal, Vol. 45, No. 4, 1950.

A typical calibration pulse is shown in figure 7. The accelerometer is a strain-gage type with a rating of 100 G. The damping is approximately 0.65 of critical and the natural frequency is stated to be 725 cycles per second. Using the shunt resistor calibration technique[4] and the manufacturer's calibration factor, a pair of horizontal lines are obtained that indicates a given value of acceleration. A computation is made to determine the weight necessary to produce this acceleration on the linear deadweight calibrator. A line is drawn along the slope of the resulting pulse to intercept a vertical line drawn at the very beginning of the pulse. The acceleration value thus determined is in perfect agreement with the value obtained using the manufacturer's calibration factor. Thus, the original calibration is shown to be still valid, in this example.

The damped natural frequency of the accelerometer may be determined by counting the number of oscillations superimposed on the calibration pulse per unit of time. The degree of damping is indicated by the height of the first over-shoot and by the rate of decay of the oscillations.[5, 6]

Conclusions

The FPL calibrator is simple in principle, inexpensive to construct, and easy to operate. With it, accelerometers are calibrated under dynamic conditions that approximate actual usage conditions. The calibration is based on fundamental properties that are easily and accurately measurable. Inaccuracies of less than ±5 percent should be possible with a carefully designed and operated calibrator. The calibrator also provides information on the natural frequency and damping ratio of the accelerometer that is being calibrated. Any change in the characteristics of an accelerometer over a period of time may be easily detected.

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[4] Harris, C., and Crede, C. Shock and Vibration Handbook, Vol. I, ch. 8, p. 34, 1961.

[5] Burns, J., and Rosa, G. Calibration and Test of Accelerometers, Statham Laboratories, Statham Instruments, Inc., Instr. Notes, No. 6, 1951.

[6] American Standards Association. American Standard Methods for the Calibration of Shock and Vibration Pickups, A. S. A. Stnd. S 2.2-1959.

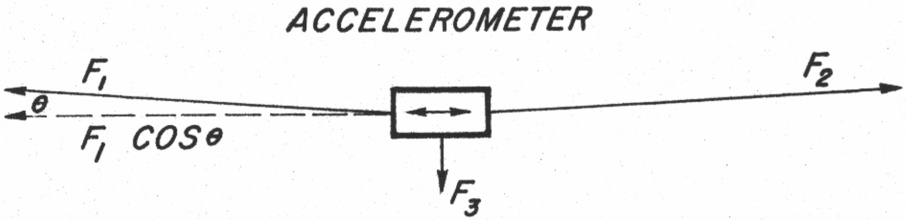

Figure 1.--Free-body diagram of balanced force system.

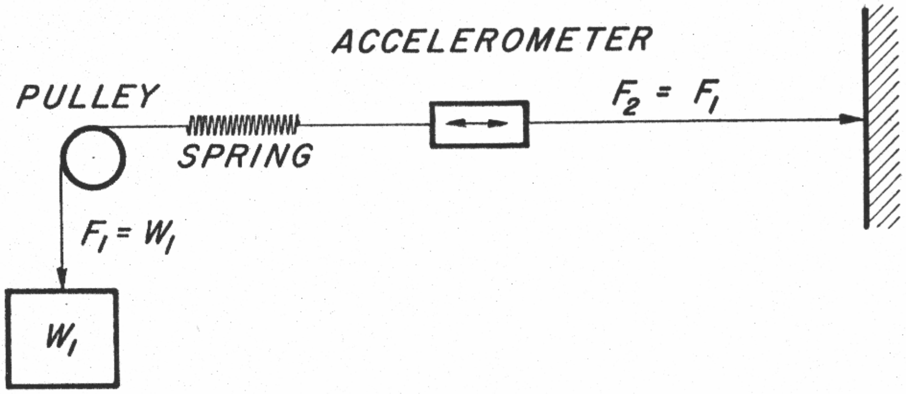

Figure 2.--Operational diagram of balanced force system.

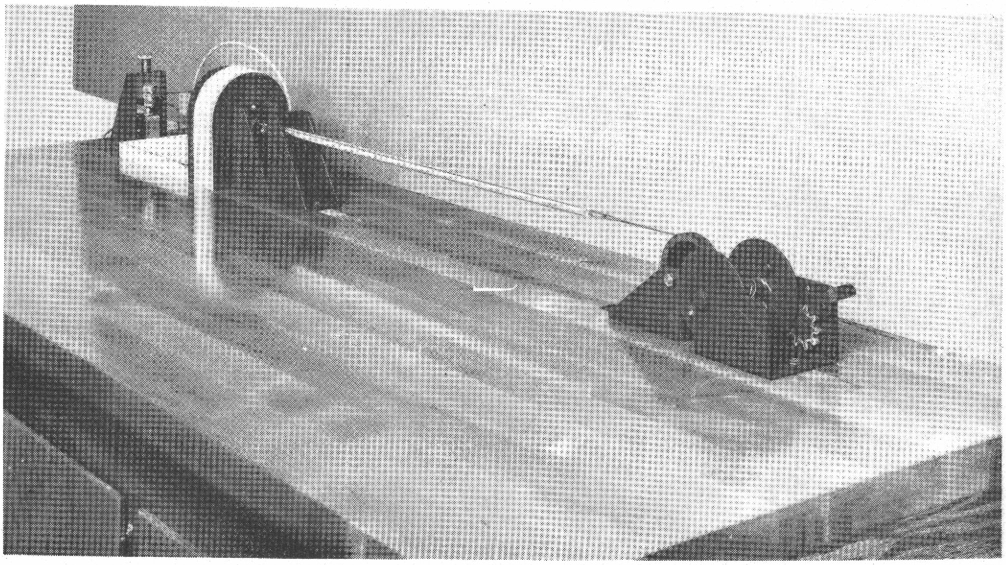

Figure 3.--Overall view of FPL linear accelerometer calibrator.

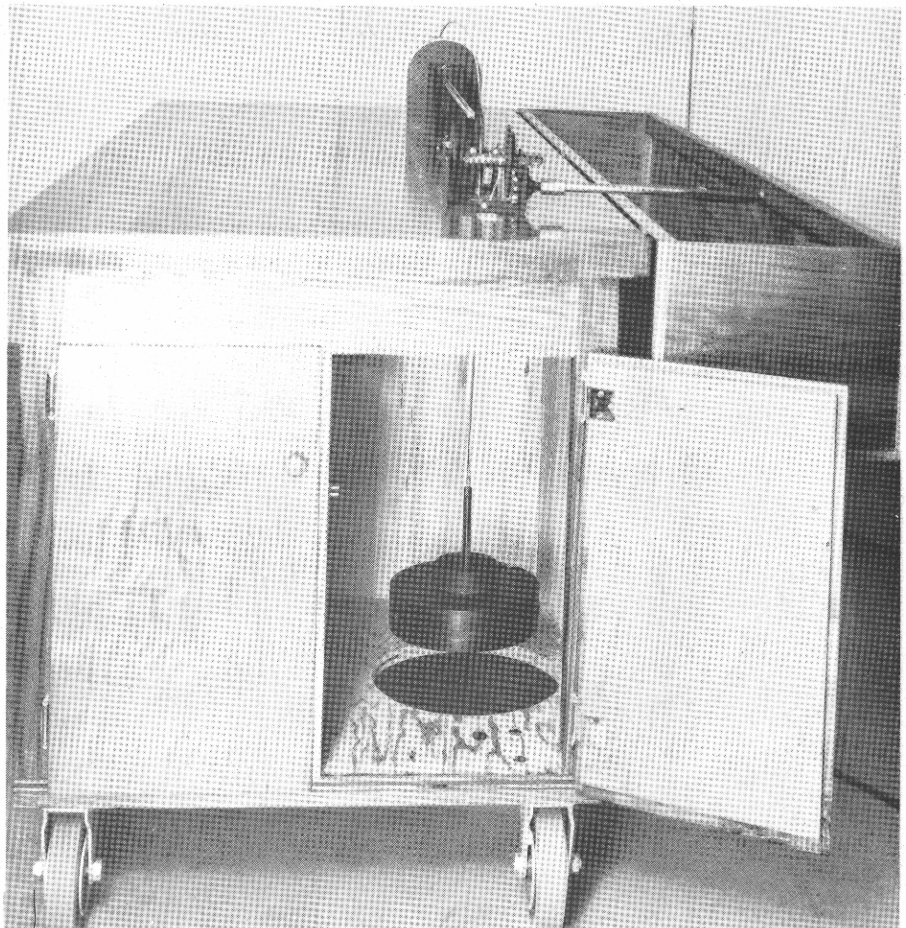

Figure 4.--End view of the calibrator shows the weights used.

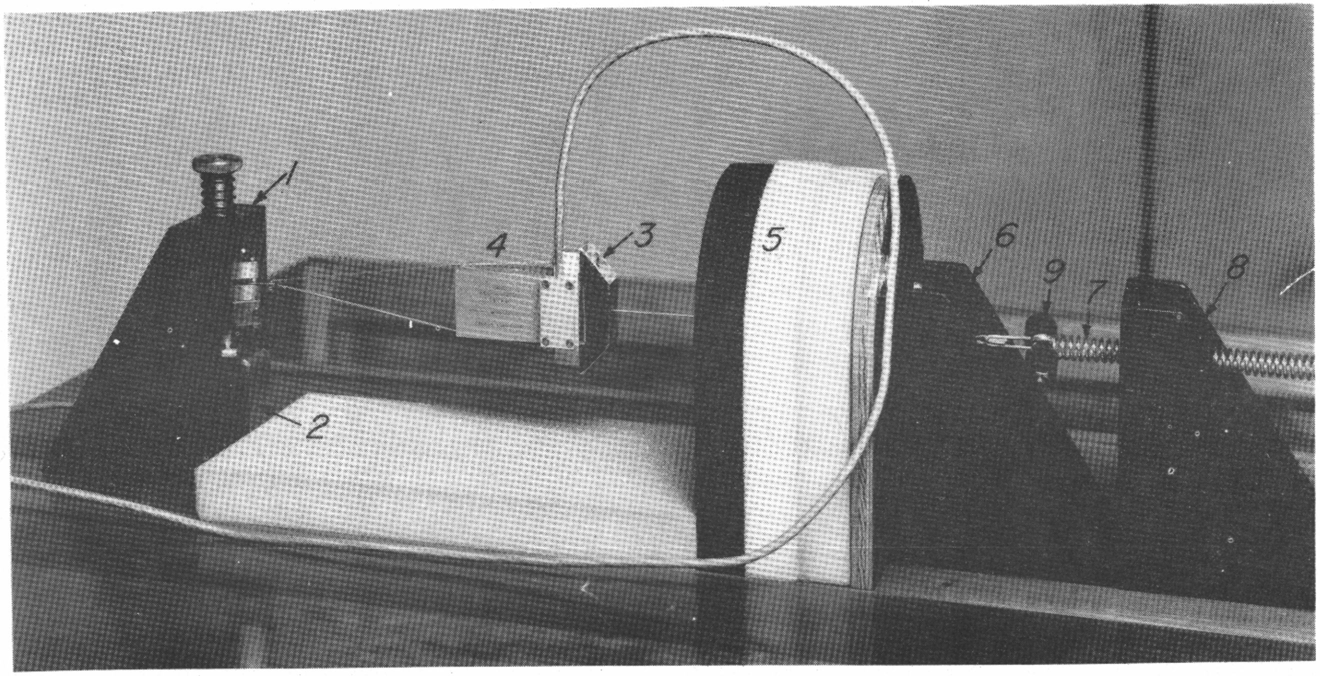

Figure 5. --Components of the FPL linear deadweight accelerometer calibrator: (1) Release mechanism, (2) triggering switch, (3) accelerometer mounting bracket, (4) accelerometer, (5) decelerating cushion, (6) cushion support bracket, (7) wire spring, (8) spring restraining bracket, and (9) snubber assembly.

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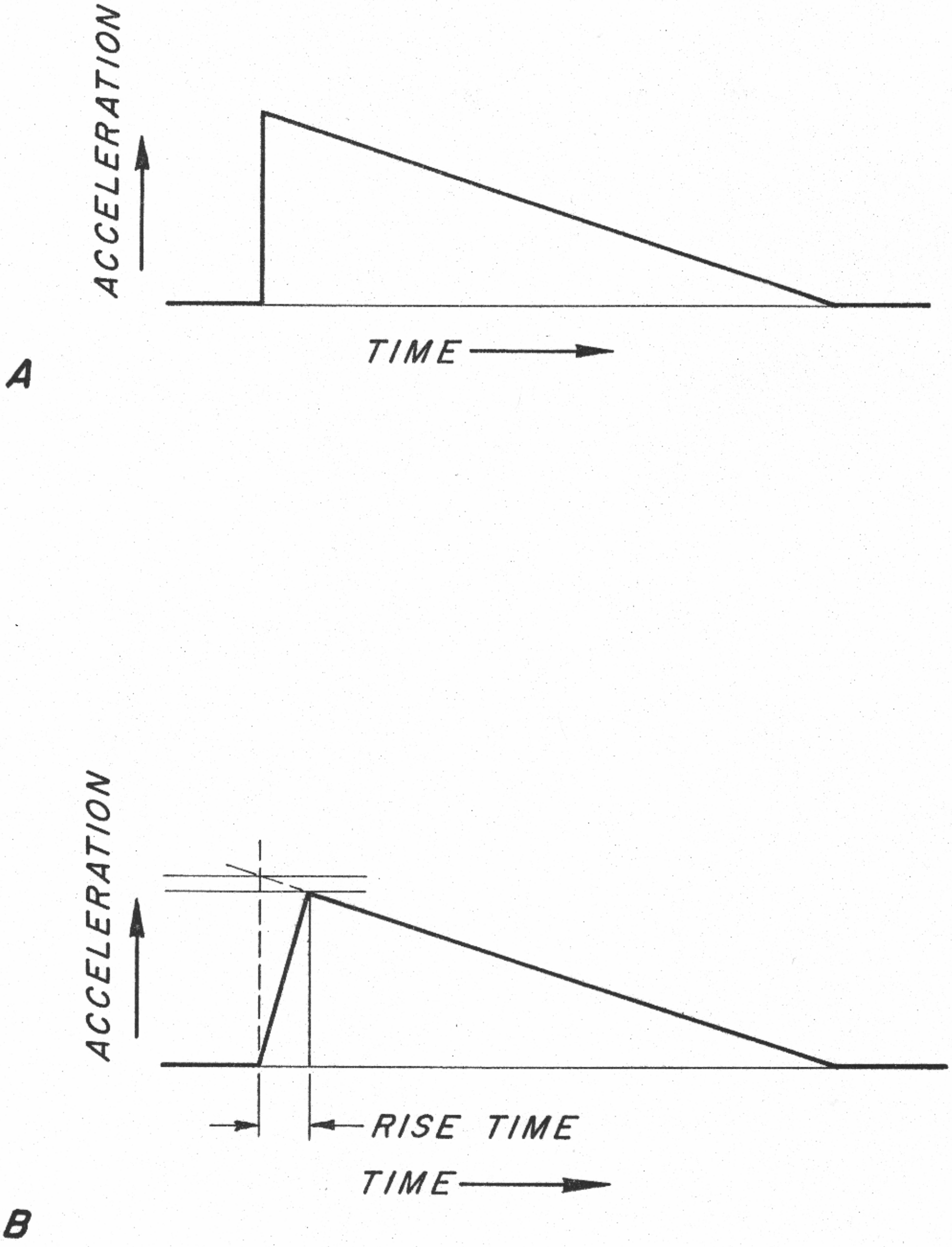

Figure 6.--A, Idealized step function of acceleration that is produced by a linear spring; B, Actual step function of acceleration that is produced by a linear spring, and construction used to obtain a corrected value of acceleration.

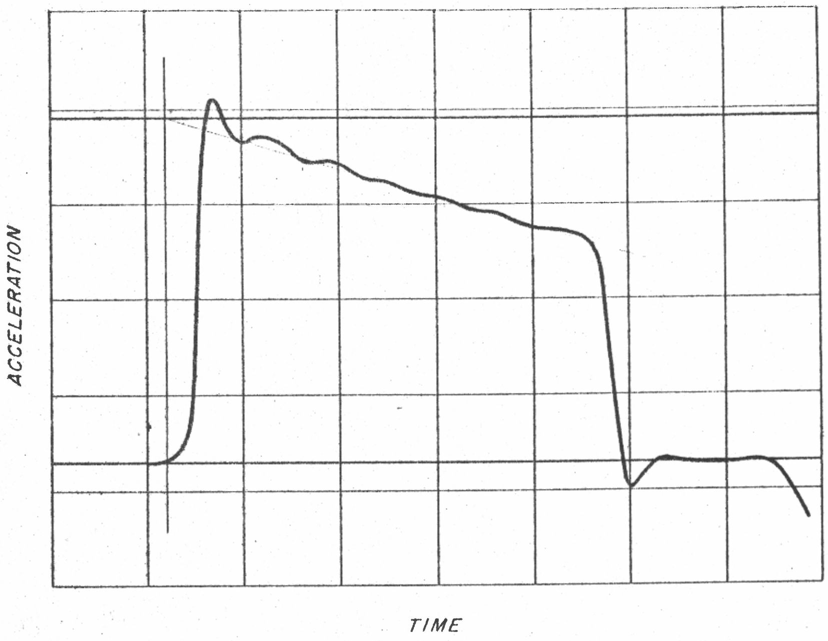

Figure 7.--Typical calibration pulse.

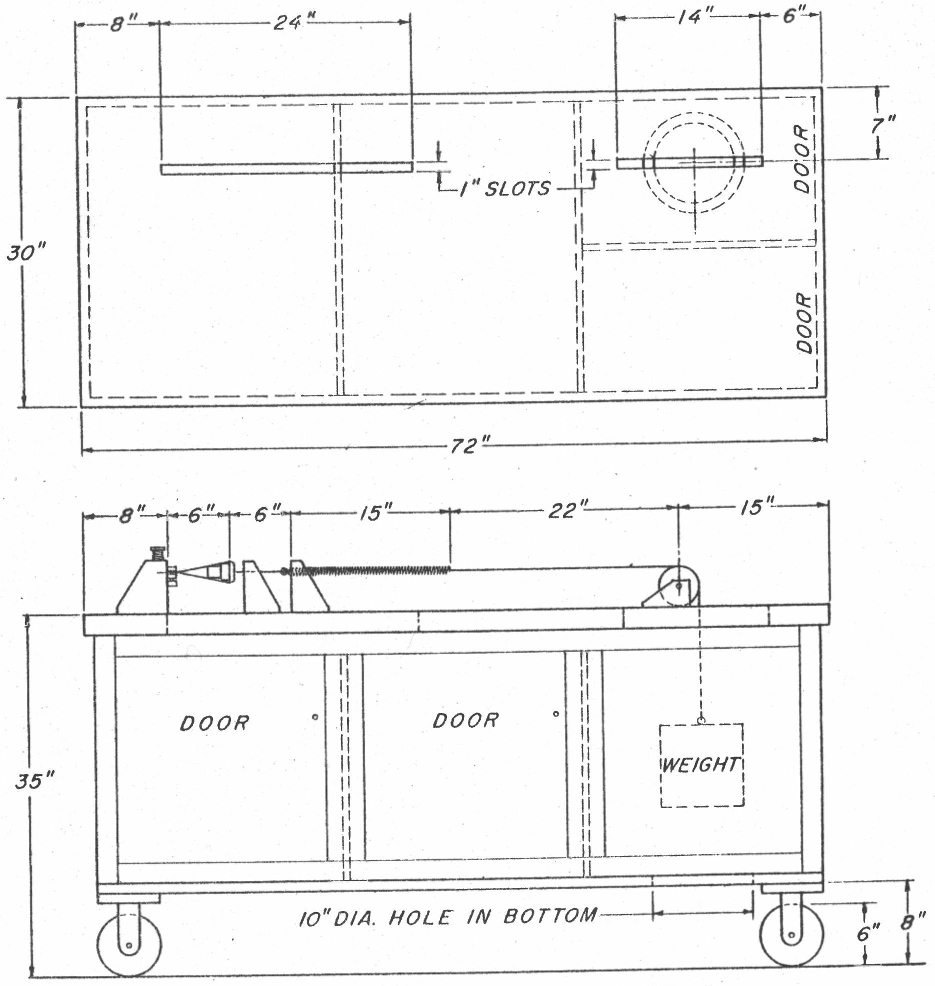

Figure 8.--Layout of calibrator and cart.