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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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No. 887

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A PORTABLE CALIBRATOR FOR DYNAMIC STRAIN GAGES

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National Bureau of Standards

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SUMMARY
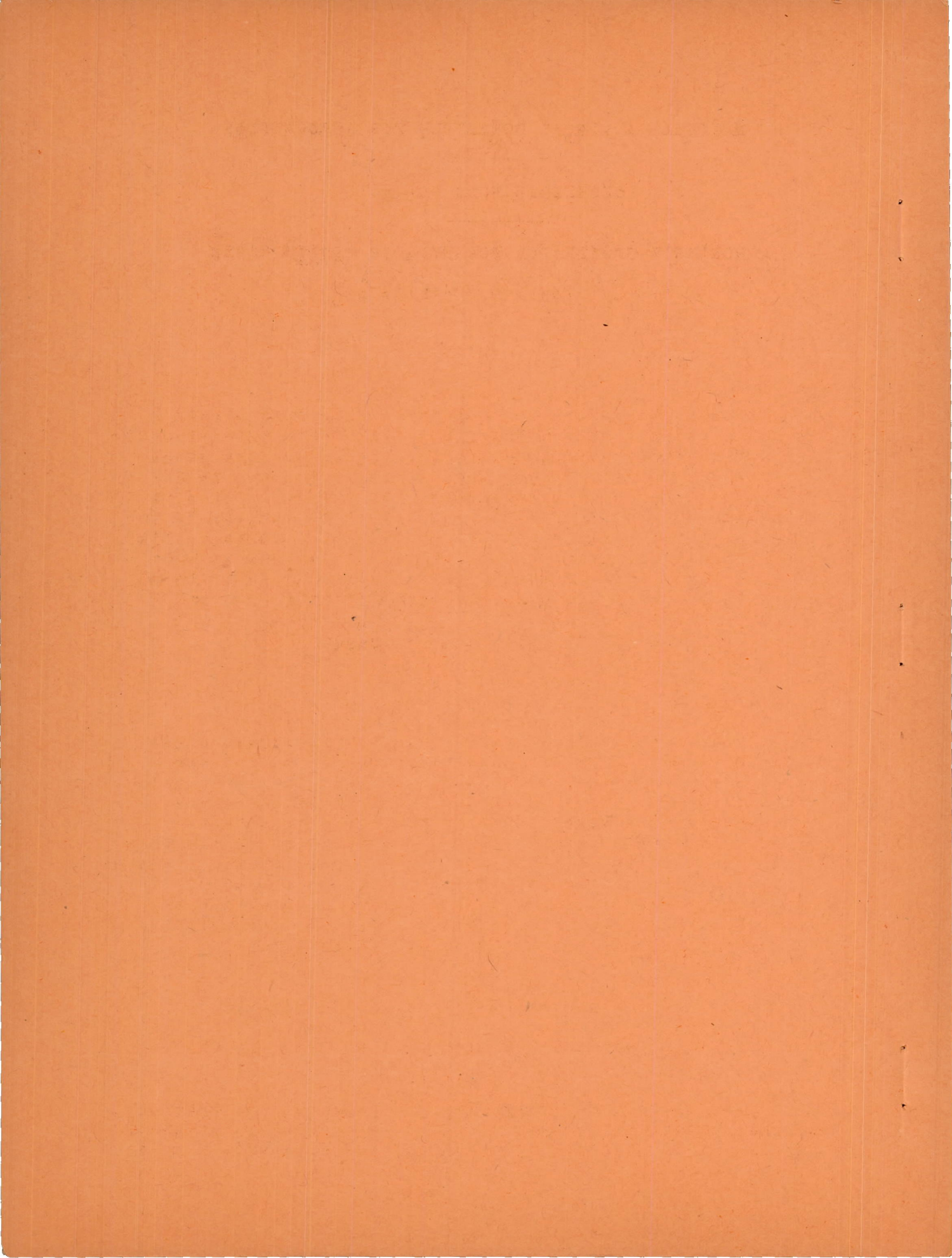
A portable device for calibrating dynamic strain
gages is described. The device contains a motor-driven
cam, which applies alternating tensile loads to a metal
strip 5/8 inch wide and $6\frac{1}{4}$ inches long. The cam is de-
signed to produce a nearly sinusoidal variation of strain
with time. Dynamic strain gages with gage lengths up to
5 inches may be calibrated by mounting them on the strip
and by changing the frequency and the amplitude of the
tensile load. The frequency may be varied from 15 to 30
cycles per second and the strain amplitude from 0 to
10×10^{-4} in steps of 2×10^{-4}.

INTRODUCTION

Dynamic strain gages are subjected to severe condi-
tions of loading and of exposure when used to measure
strains on airplanes in flight. It is desirable to cali-
brate them frequently after use in order to check that
the measurements were made with the gages in working
order. The portable dynamic calibrator described in this
report was developed at the National Bureau of Standards,
at the request of the National Advisory Committee for
Aeronautics, in order to facilitate the calibration of
dynamic strain gages at locations where the larger labo-
ratory type of calibrators are not available.

CONSTRUCTION AND OPERATION OF THE CALIBRATOR

Principles of Operation

The portable calibrator is a device for calibrating
dynamic strain gages by mounting them on a strip of sheet
metal, which is then subjected to known alternating strain.

Calibration consists in a comparison of the output of the strain gage with the known applied strain.

The principles of operation of the calibrator may be understood by reference to figures 1 and 2. The strip of metal on which the strain gage is mounted is designated B. This strip is subjected to an alternating strain of known frequency and amplitude as follows: The right end of the strip is clamped in the fixed clamp C; the left end, in the movable clamp D. The movable clamp is free to rock about the bearing E. A rocking motion of the clamp is produced by the cam F, which is driven by the electric motor shown in figure 2. The rocking motion is of sufficiently small amplitude that the displacement of clamp D relative to clamp C is practically axial. This relative displacement produces an alternating tensile strain in the strip. The amplitude of the strain may be varied by changing the eccentricity of cam F; the frequency, by changing the speed of the motor driving the cam. The strip is assembled under sufficient initial tension that it will not buckle during the compression stroke of the alternating motion of D. A damper A is provided to prevent lateral whipping of the strip.

Design

Materials used in the construction of the various parts of the portable calibrator are given in table I. Details of construction of the calibrator are shown in figures 3 to 9. These details differ from the details of the experimental calibrator shown in figure 2 in three respects:

1. The double cam F in figure 2 proved cumbersome for adjustment and is replaced by the composite cam shown in detail in figure 7. This composite cam was designed from information gained from the use of the double cam and the two cams are similar in essential details. The composite cam has not been constructed since there is no reason for supposing that it will function differently from the double cam and since the greater convenience of adjustment is obvious.

2. The motor base in figure 2 was assembled from material that happened to be immediately available. A simple and more rugged design of base is given in figure 8.

3. The stroboscopic sleeve G, shown in figure 2, is replaced by the marked coupling, shown in figures 9 and 10, in order to save space.

The total weight of the calibrator (fig. 2) was about 57 pounds.

Assembly

The calibrator may be assembled by following the drawings in figures 3 to 9 except for the cam sleeve, piece 13, in figure 7 and the motor shims in figure 10. The dimensions for these pieces are determined after the calibrator has been assembled.

The eccentricity of the cam is experimentally determined in order to obtain strain increments close to 2×10^{-4}. The following procedure is used: Mount a strip, piece 22 (fig. 11), tightly in the jaws using a standard bar, piece 24 (fig. 11), to determine the free length of strip between the jaws. Put the damper, piece 27 (fig 9), on the back of the strip with rubber bands about 1/2 inch from each end. Place the jack, piece 25 (fig. 11), in the shaft hole and adjust the screw in such a way that the bell crank is near the camshaft end of its swing. (See detail of jack assembly, fig. 11.) Place a strain gage at the center of the strip and apply a strain of about 2×10^{-4} by tightening the nut, piece 26 (fig. 3). Locate a dial gage on the frame to measure the rise of the lever at the jack. (See detail of jack assembly, fig. 11.) Increase the strain in the strip by several steps up to about 22×10^{-4} by raising the lever at the jack, and measure the rise and the strain at each step.

Plot the strain against the rise as shown in figure 12. Fair a line through the points and from the line determine the rise corresponding to a strain of 10×10^{-4}. In figure 12, this rise was equal to 0.204 inch.

The eccentricity e of the composite cam, piece 13 (fig. 7), corresponding to an amplitude of rise equal to 0.204 inch is equal to one-half the rise, or 0.102 inch. The cam can now be machined in accordance with figure 7 by use of the experimentally determined value of e.

The shims under the motor (fig. 10) are chosen after assembly in order to obtain accurate alinement between the cam and the motor. This alinement is necessary because

the armature of the motor is rigidly connected to the cam
in order to utilize it as a flywheel on the camshaft.

The electric circuits in figure 11 are for the motor
used on the experimental model in figure 2. The circuits
may have to be modified in any given case to suit avail-
able equipment.

Operation and Calibration

The first operation to be performed on the completed
calibrator is to determine accurately the strain amplitude
caused by each setting of the cam.

For this purpose the calibrator may be placed over
the edge of a table as shown in figure 10. A strip, piece
22 (fig. 11), is clamped in the jaws, with the standard
bar used to determine the free length; and the damper,
piece 27 (fig. 9), is attached to the strip with rubber
bands at each end as shown in figure 2. In order to set
the cam to a nominal amplitude, the indexing pin, piece 15
(fig. 7), is removed from the cam; the outer ring of the
cam is rotated until the numbers indicating nominal ampli-
tude coincide; and the indexing pin is replaced and tight-
ened in the outer ring hole marked with the nominal ampli-
tude. The tension nut, piece 26 (fig. 3), is tightened
to bring the bell-crank shoe against the cam. A calibrated
strain gage is placed on the strip near its center to ad-
just the initial tension; (that is, the tension in the
strip when the bell crank is in its lowest position rela-
tive to the camshaft). The lowest position can be found
by observing either the strain or the motion of the bell
crank as the cam is turned by hand. With the bell crank
in the lowest position, the strain is first released by
loosening the tension nut and is then reapplied so that
it has a value of about 2×10^{-4} when the tension nut is
locked with the lock nut. The calibrator should be oper-
ated for a few cycles and the gage reading at the minimum
should be checked to insure that the strip has not slipped
in the jaws. A decrease in the reading indicates that the
jaws have slipped. The jaws should then be readjusted and
the setting should be repeated. The strain amplitude for
the nominal setting chosen is measured by the strain gage
when the machine is operating at 30 cycles per second.
This procedure is repeated to determine the strain ampli-
tude for the remaining cam settings.

The angular speed of the cam may be adjusted to 15
and 30 cycles per second by moving the rheostats until

either the 15- or the 30-cycle marking on the stroboscopic
sleeve appears stationary when the neon light is connected
to a 60-cycle alternating-current line. Intermediate fre-
quencies can be measured with a suitable tachometer.

During operation the bearings should be lubricated
with SAE 10 motor oil. The cam face should be lightly but
frequently lubricated with SAE 90 hypoid gear oil or with
vaseline.

PERFORMANCE TESTS

The strain gage used in most of the tests described
in this report was a 2-inch Tuckerman optical strain gage
with 0.2-inch lozenge and with a regular flat specimen
knife edge. A preliminary run with a lightweight Tuckerman
gage had shown that the error due to elastic deformation of
the strain gage by the vibration in the strip was too small
to be measured even at the highest cam setting and the max-
imum speed (30 cycles per sec). The gage was read with a
Tuckerman autocollimator equipped with a reticule for vi-
bratory strains. This procedure permitted observation of
the strain at the extreme positions to within $\pm 0.05 \times 10^{-4}$.

Wave Form

The variation of strain in the calibrating strip B
(fig. 1) with time should be approximately sinusoidal; a
marked deviation from a sinusoidal wave form in the output
of the strain pickup may therefore be used to indicate
distortion.

The wave form of the strain in the strip was observed
by mounting a Baldwin Southwark SR-4 wire strain gage on
the center of the strip and recording its output with a
cathode-ray oscilloscope. Figure 13 shows the wave form
on the screen of the oscilloscope for the maximum cam set-
ting and at a frequency of 30 cycles per second. The hori-
zontal line is the indication for zero dynamic strain out-
put of the SR-4 gage. The wave form is seen to be a close
approximation to a sine curve. A sinusoidal variation was
also observed at other frequencies and at other cam settings.

Effect of Replacement of Strip and of Change in Frequency

The strain amplitude for a given cam setting should be the same after replacement of the strip by a new strip of the same material and the same dimensions. The strain amplitude should be the same over the range of recommended operating speeds.

The effect on strain amplitude of replacement of the strip was tested by successively setting up five strips in the calibrator and using an initial tensile strain of 2×10^{-4}. The strain excursion for the maximum cam setting was determined for 15 and for 30 cycles per second in order to determine the effect of change in frequency on the strain amplitude. The results are given in table II. The strain amplitude for the maximum cam setting for the five different strips was equal within ±1 percent to the average value of 10.6×10^{-4}. The change in strain amplitude due to increasing the frequency from 15 to 30 cycles per second was too small to be measured.

Effect of Initial Tension

The strain amplitude for a given cam setting should be the same for variations in the initial tension of the calibrating strip that might occur in clamping the strip.

A change in initial tensile strain in the strip from 2×10^{-4} to 4×10^{-4} did not change the strain amplitude for the maximum setting by a measurable amount. It is inadvisable to carry the initial strain above 4×10^{-4} inasmuch as fatigue failure may result after a short period of use.

Uniformity of Strain Distribution in Strip

The strain in the calibrating strip should be uniform in order that the strain impressed on the pickup will be the same for a given cam setting, regardless of the gage length of the pickup.

The variation of strain in the strip was measured as follows: The strip was set up for an intermediate value of amplitude and the calibrator was operated at 30 cycles per second. The strain amplitude at several positions along the strip was measured with a 2-inch Tuckerman gage. The results are given in figure 14. The strain amplitude

is seen to be constant within the order of accuracy of observation over the center 5 inches of the strip.

Effect of Mass of Gage for Given Cam Setting

The strain amplitude in the calibrating strip should not be affected by the inertia effects introduced by the mass of the strain pickup. The calibrator was tested for this effect as follows: An SR-4 wire strain gage was attached to the strip to measure the strain amplitude. A dummy gage, having a length of 2 inches and weighing 5.8 ounces, was mounted on the specimen with its points spanning the SR-4 gage. The calibrator was operated at maximum strain amplitude (10.6×10^{-4}) at 15 and at 30 cycles per second and the strain was measured at each frequency with and without the dummy gage attached. The effect of the 5.8-ounce gage on the strain amplitude was less than the observational error in the strain measurement.

CONCLUSIONS

The dynamic calibrator appears suitable for the calibration of dynamic strain gages at strain amplitudes varying in five steps from 2×10^{-4} to 10×10^{-4} and at frequencies from 15 to 30 cycles per second. The error in the applied strain amplitude should not exceed 1 percent of its maximum value of 10×10^{-4}, provided that the gage has a gage length not exceeding 5 inches and a weight not exceeding 6 ounces.

National Bureau of Standards,
    Washington, D. C., November 9, 1942.

TABLE I

MATERIALS USED IN CONSTRUCTION OF PORTABLE CALIBRATOR

Piece		Number of pieces required	Material
Designation on figure	Name		
1	Frame	2	Cold-rolled steel
2		1	Do.
3 }	Spacer	1	Do.
4		1	Do.
5	Lever	1	17S-T aluminum alloy
6	Trunnion	1	Annealed cold-rolled steel
7	Clamp	1	Do.
8 }	Clamping bar	1	Do.
9		1	Do.
10	Bearing collar	2	Do.
11	Cam follower shoe	1	Bearing metal
12	Cam surface	1	Annealed cold-rolled steel
13	Cam sleeve	1	Do.
14	Camshaft	1	Cold-rolled steel
15	Indexing pin	1	Drill rod (SAE 1095)
16	Motor base	1	Annealed cold-rolled steel
17	Bearing, trunnion	2	Bearing metal
18	Motor sub-base	1	Oak
19	Bearing, shaft	2	Bearing metal
20	Coupling	1	Cold-rolled steel
21	Trunnion, spacer	2	Do.
22	Strip		24S-T aluminum alloy
23	Lamp bracket	1	Brass
24	Bar	1	Cold-rolled steel
25	Jack	1	Do.
26	Tension nuts	2	5/16 SAE
27	Damper	1	Brass, rubber

Assembly screws, 1/4 in. by 28 by 3/4 in. recess head capscrews

TABLE II

STRAIN AMPLITUDE FOR MAXIMUM CAM SETTING

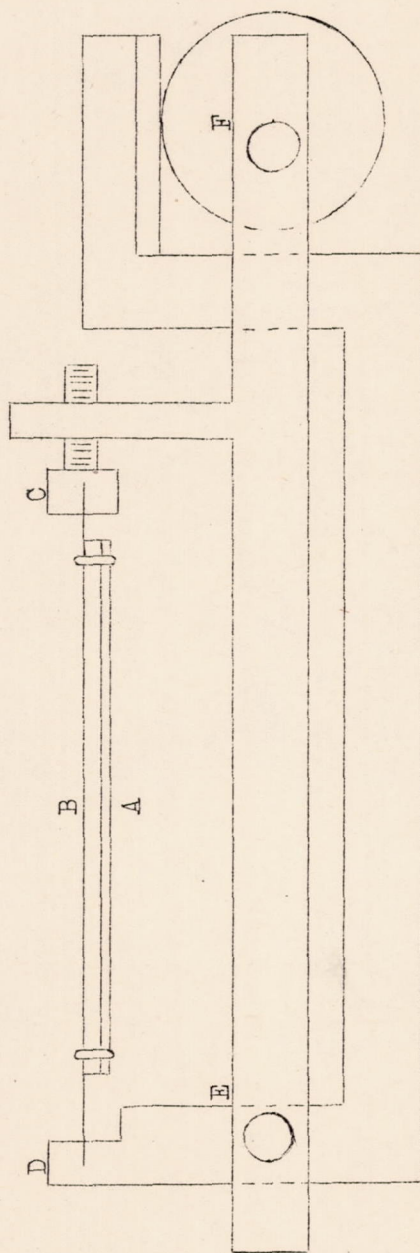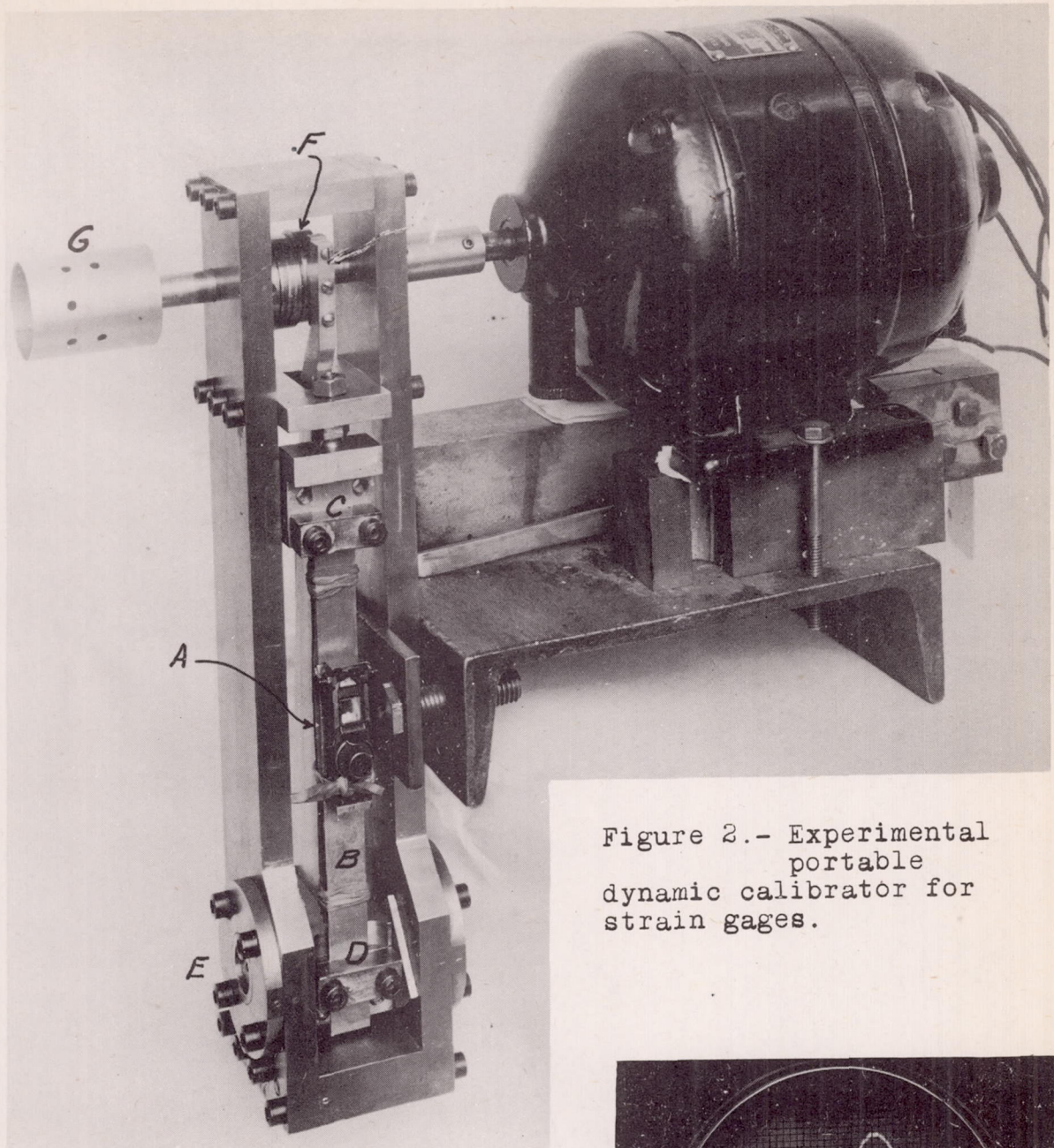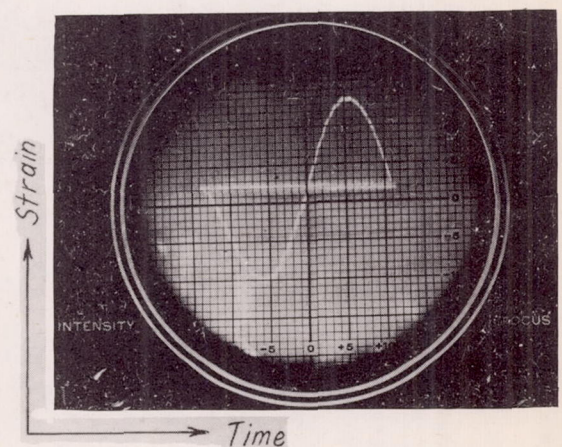| Frequency (cycles/sec)	Strain amplitude	
Strip	15	30
1	10.65×10^{-4}	10.65×10^{-4}
3	10.50	10.50
4	10.65	10.65
5	10.55	10.55
7	10.70	10.70

Figure 1.- Schematic diagram of calibrator.

Figure 2.- Experimental portable dynamic calibrator for strain gages.

Figure 13.- Wave form from calibrator for maximum cam setting. Strain amplitude, 10×10^{-4}; frequency, 30 cycles per second.
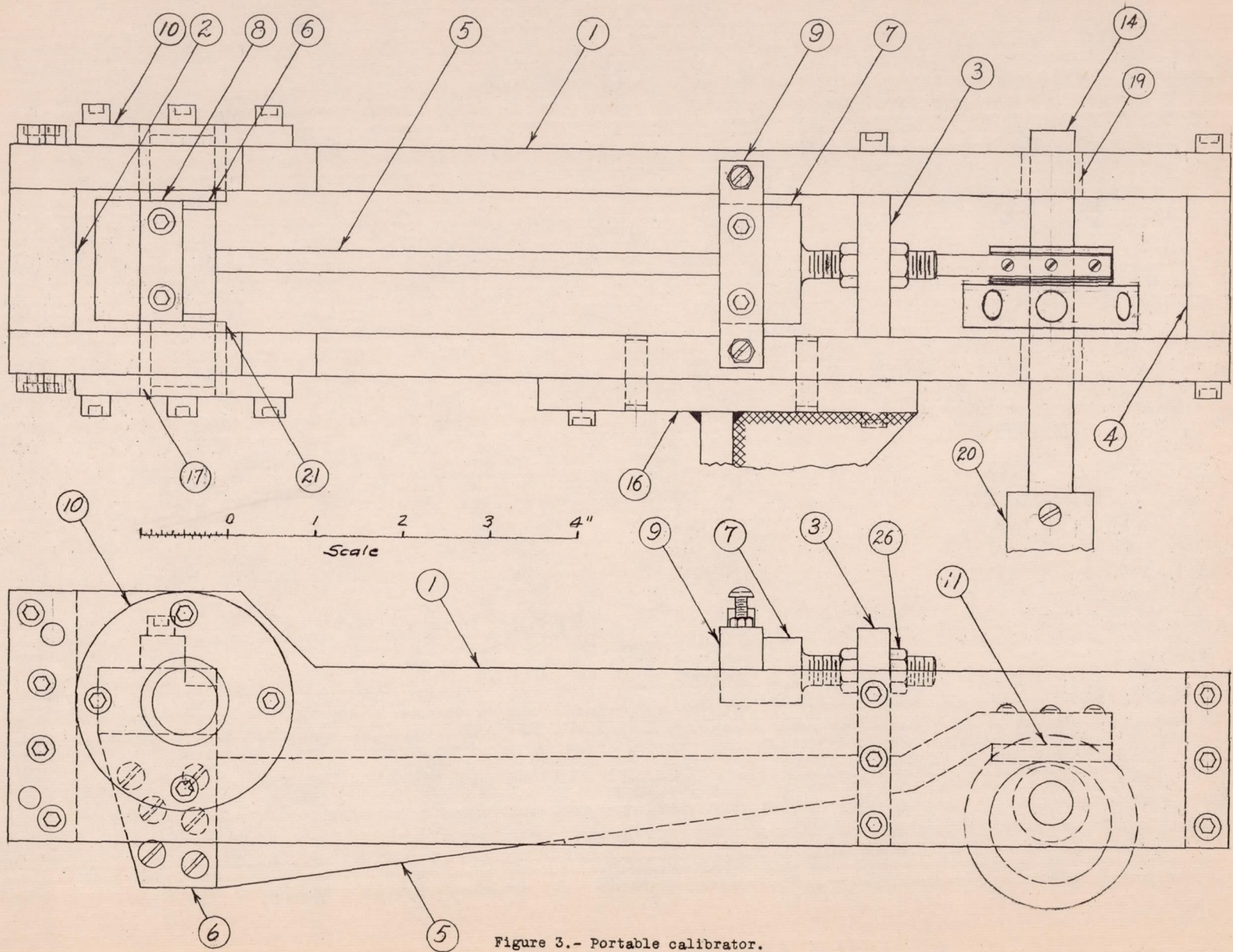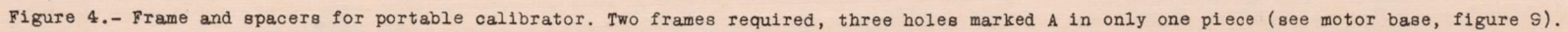
Figure 3.- Portable calibrator.

Scale

0   1   2   3   4"
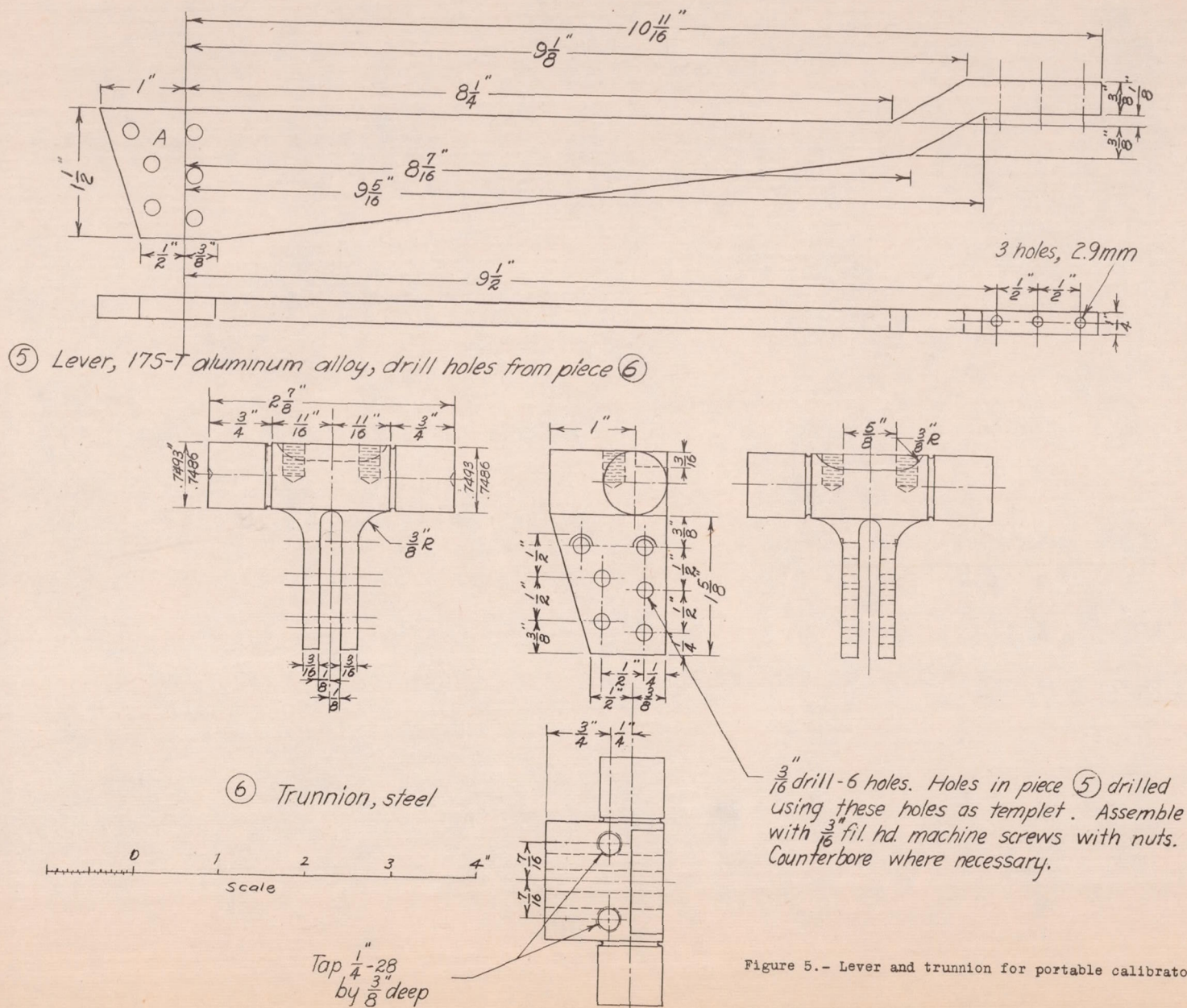
Figure 3.- Portable calibrator.

Fig. 3

Fig. 4

Figure 4.— Frame and spacers for portable calibrator. Two frames required, three holes marked A in only one piece (see motor base, figure 9).

⑤ Lever, 17S-T aluminum alloy, drill holes from piece ⑥

3 holes, 2.9mm

⑥ Trunnion, steel

Tap $\frac{1}{4}$-28
by $\frac{3}{8}$" deep

Scale

$\frac{3}{16}$" drill - 6 holes. Holes in piece ⑤ drilled
using these holes as templet. Assemble
with $\frac{3}{16}$" fil. hd. machine screws with nuts.
Counterbore where necessary.

Figure 5.- Lever and trunnion for portable calibrator.

Fig. 5

⑦ Clamp. steel

⑧ Clamp bar, steel

⑨ Clamp bar, steel

Scale

⑩ Bearing collar, steel
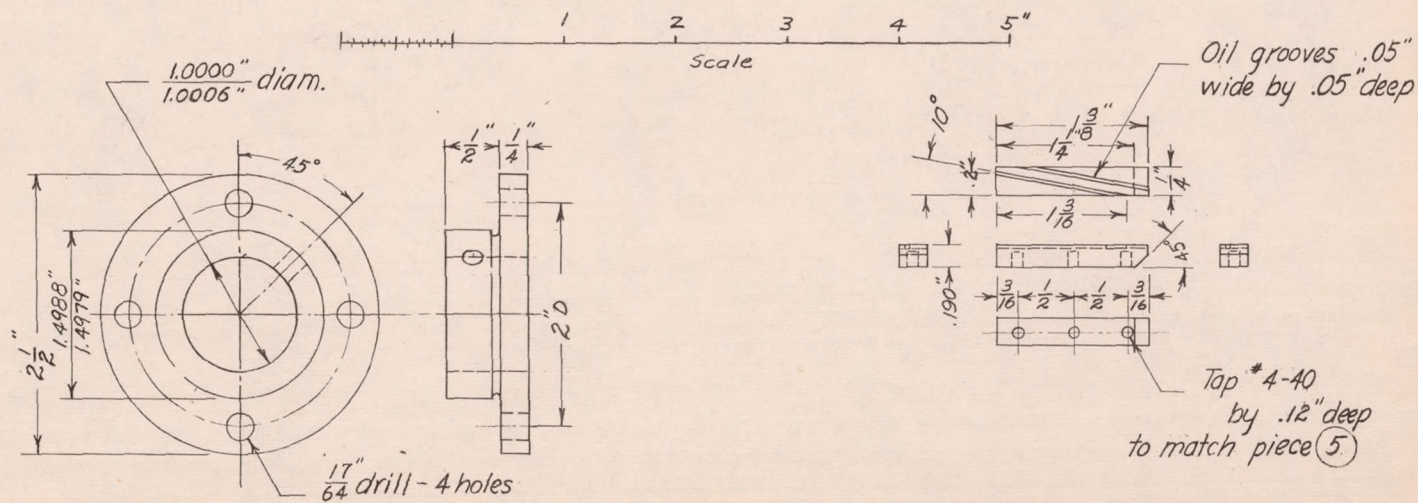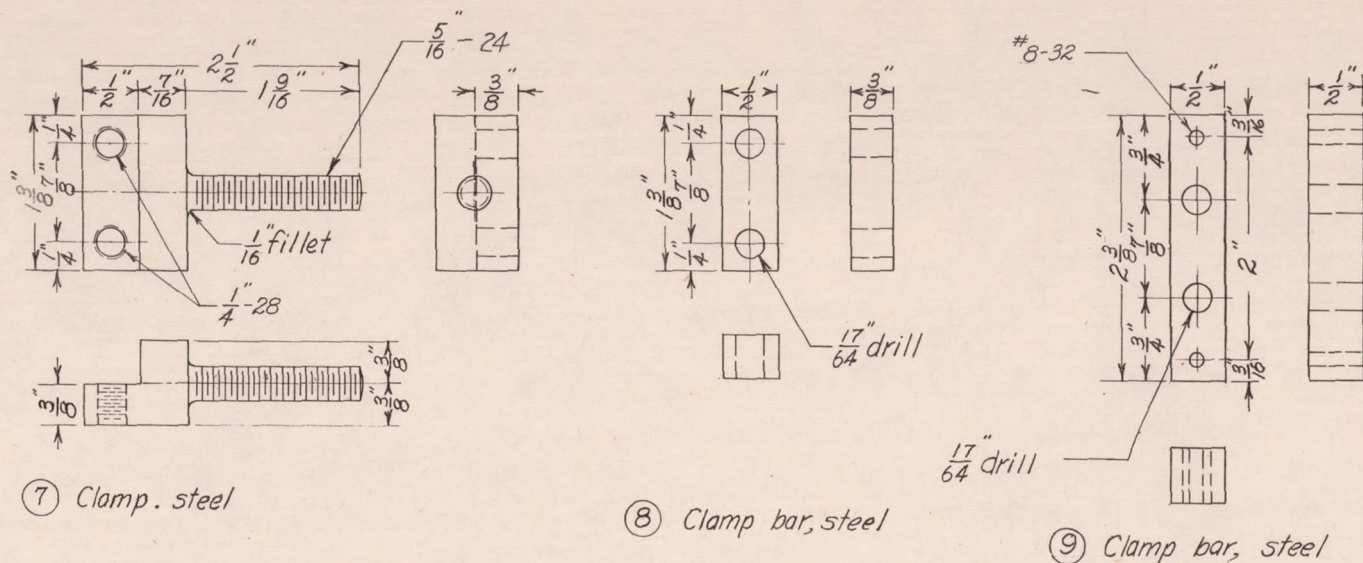
⑪ Cam follower shoe, bearing metal, federal (copper, lead, tin).

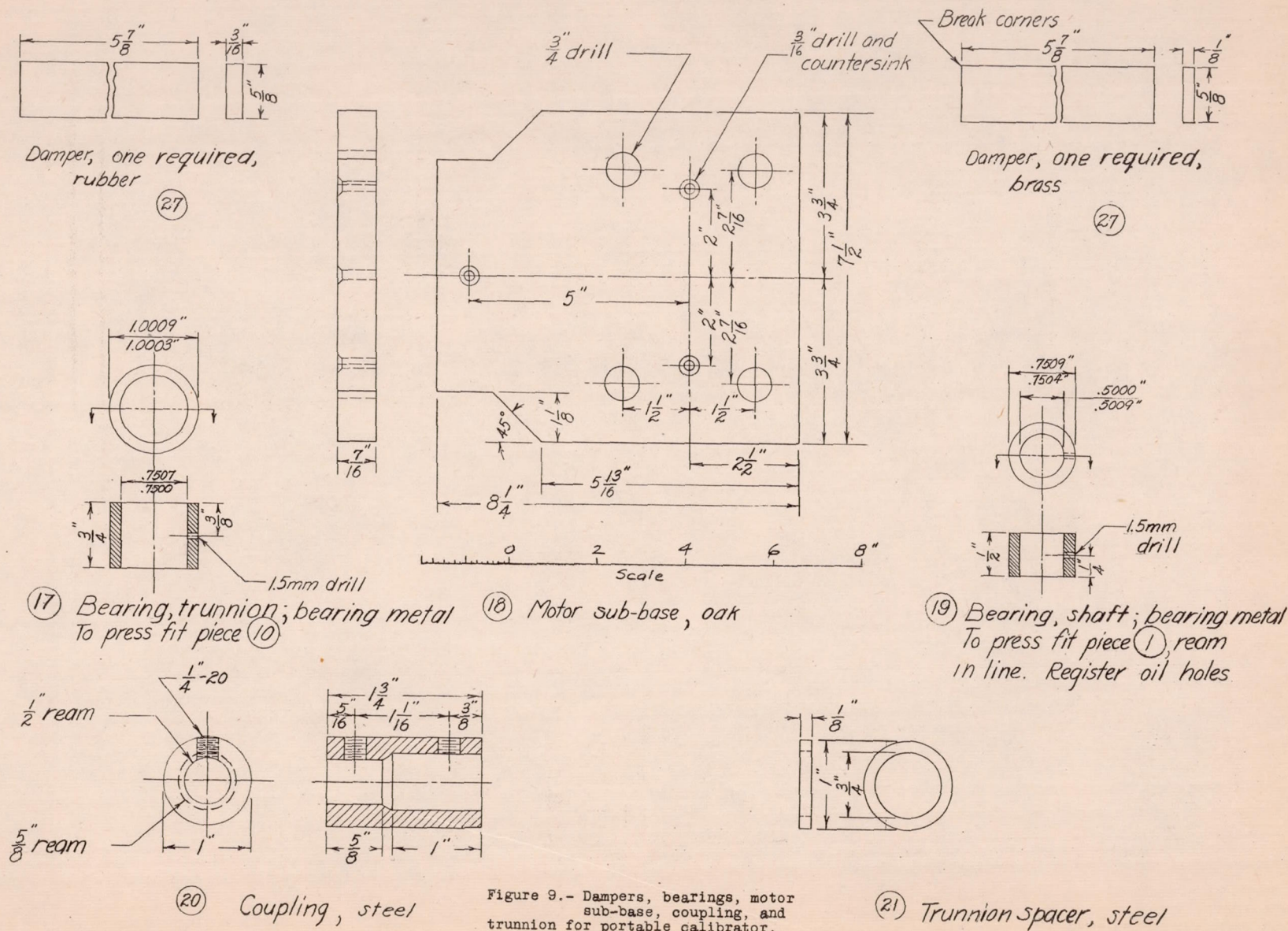Figure 6.- Clamp, clamping bars, bearing collar, and cam follower shoe for portable calibrator.

Fig. 6

Figure 7.- Composite cam for portable calibrator.

Fig. 7

Center of motor mounting holes

$\frac{7}{16}''$ drill
4 holes

$\frac{1}{4}''$ clearance drill

Piece ①

Drill and ream for $\frac{1}{4}''$ pin

Top #10-32
3 holes

Holes in plate above are to match piece ① as shown at right

For MD 145 K Westinghouse motor includes $\frac{1}{8}''$ for shims

scale

⑯ Motor base, steel

Figure 8.- Motor base for portable calibrator.

Fig. 8

12-28-41

$5\frac{7}{8}$" $\frac{3}{16}$" $\frac{5}{8}$"

Damper, one required, rubber

(27)

$\frac{3}{4}$" drill

$\frac{3}{16}$" drill and countersink

Break corners

$5\frac{7}{8}$" $\frac{1}{8}$" $\frac{5}{8}$"

Damper, one required, brass

(27)

1.0009"
1.0003"

.7507
.7500

$\frac{3}{4}$"
$\frac{3}{8}$"

1.5mm drill

(17) Bearing, trunnion; bearing metal
To press fit piece (10)

$\frac{7}{16}$"

$2\frac{7}{16}$"

$2\frac{7}{16}$"

$3\frac{3}{4}$"

$7\frac{1}{2}$"

$3\frac{3}{4}$"

5"

$1\frac{1}{2}$" $1\frac{1}{2}$"

45° $\frac{1}{8}$"

$8\frac{1}{4}$"

$5\frac{13}{16}$"

$2\frac{1}{2}$"

0   2   4   6   8"
Scale

(18) Motor sub-base, oak

.7509
.7504"

.5000"
.5009"

$\frac{1}{2}$" $\frac{1}{4}$"

1.5mm drill

(19) Bearing, shaft; bearing metal
To press fit piece (1), ream
in line. Register oil holes

$\frac{1}{4}$"-20

$\frac{1}{2}$ ream

$\frac{5}{8}$" ream

1"

$1\frac{3}{4}$"
$\frac{5}{16}$" $1\frac{1}{16}$" $\frac{3}{8}$"

$\frac{5}{8}$" 1"

(20) Coupling, steel

Figure 9.- Dampers, bearings, motor
sub-base, coupling, and
trunnion for portable calibrator.

$\frac{1}{8}$"

1" $\frac{3}{4}$"

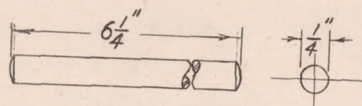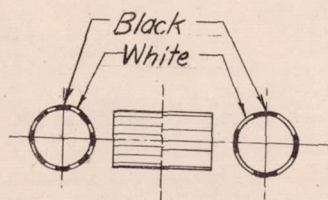(21) Trunnion spacer, steel

Fig. 9
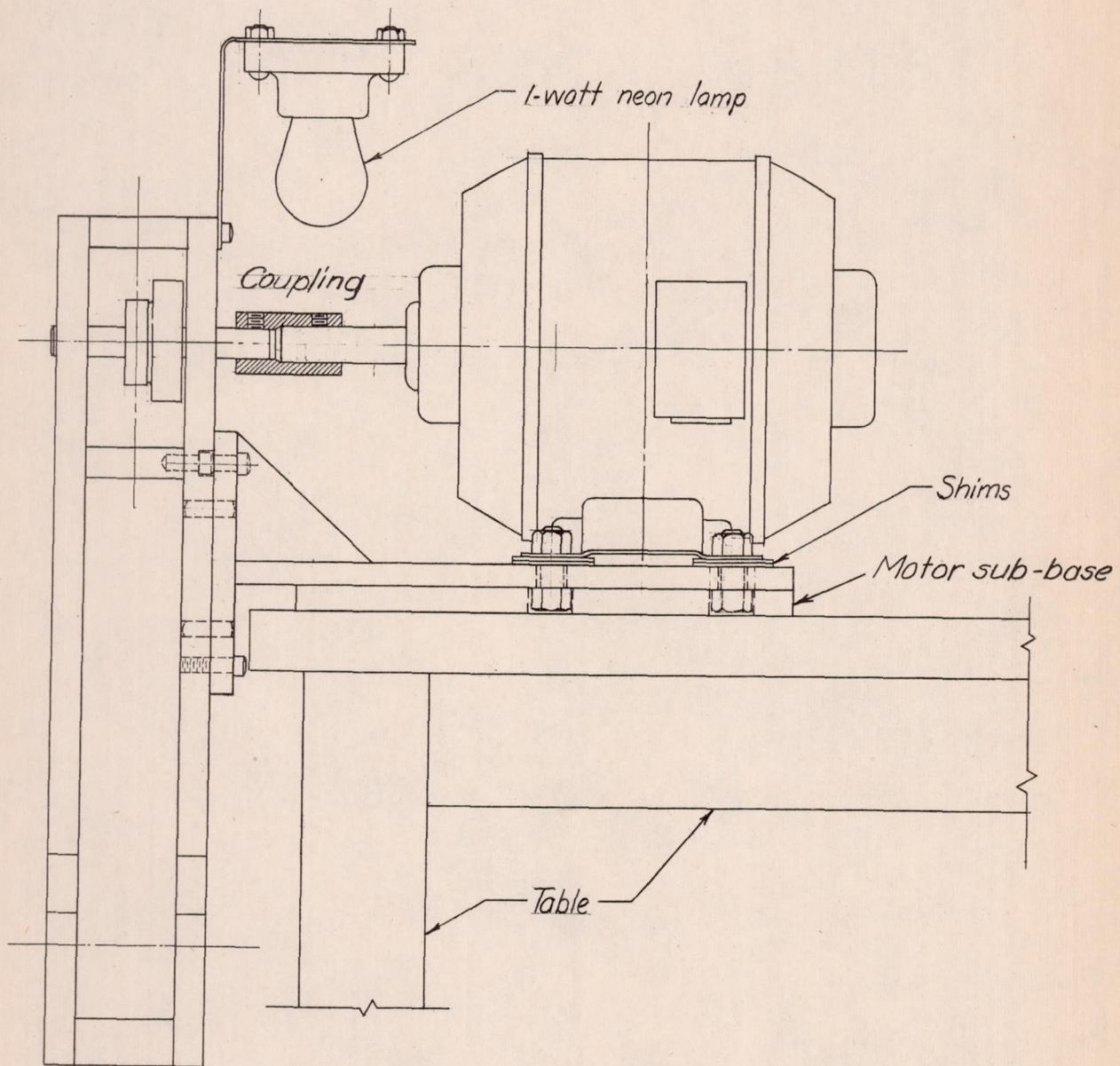
Figure 10.- Portable calibrator.

1-watt neon lamp

110-volt ac

Shunt field

Armature

56 ohms 3.3 amperes

.9 ohms 25 amperes

110-volt dc

Wiring diagram for Westinghouse
M.D 145K shunt motor

7 1/2"

.032"

5/100"
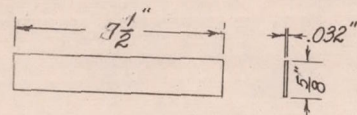
(22) Standard strip,
24 S-T aluminum alloy

0   2   4"

6 1/4"

1/4"

(24) Standard bar, steel

Tap 10-32

10-32 by 2"

1 1/2"   1 1/2"

1/2"

3"

(25) Jack, steel

Black
White

Coupling coloring for
strobscopic effect

Drill to match
lamp base

1/4" R

3"

1/16"

2"

3 1/2"

1/4" clearance
drill

1/4"
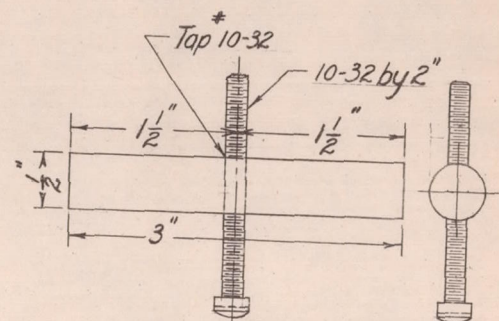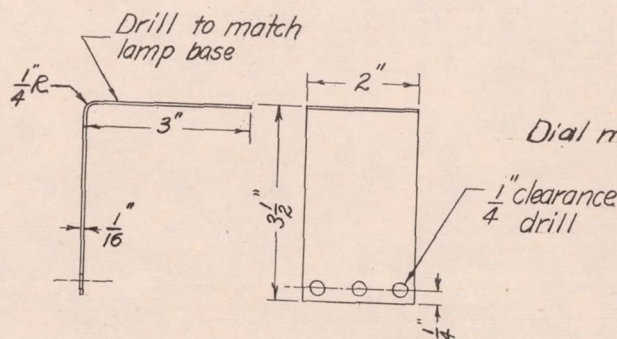
(23) Lamp bracket, brass

0   2   4"
scale

Dial micrometer
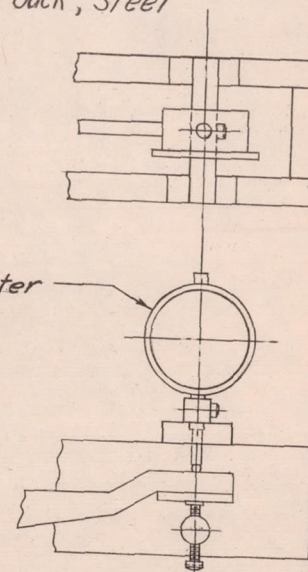
Jack assembly

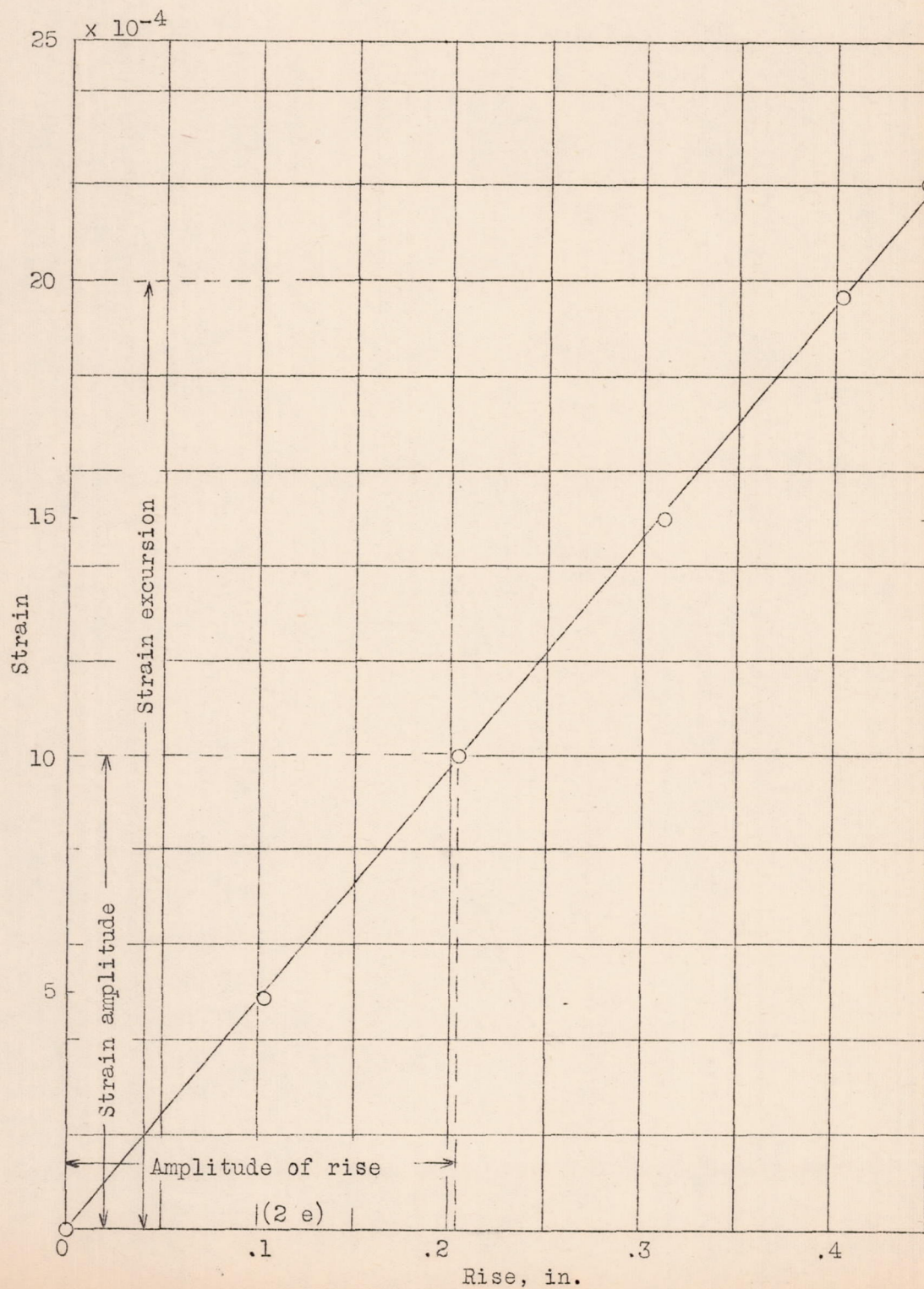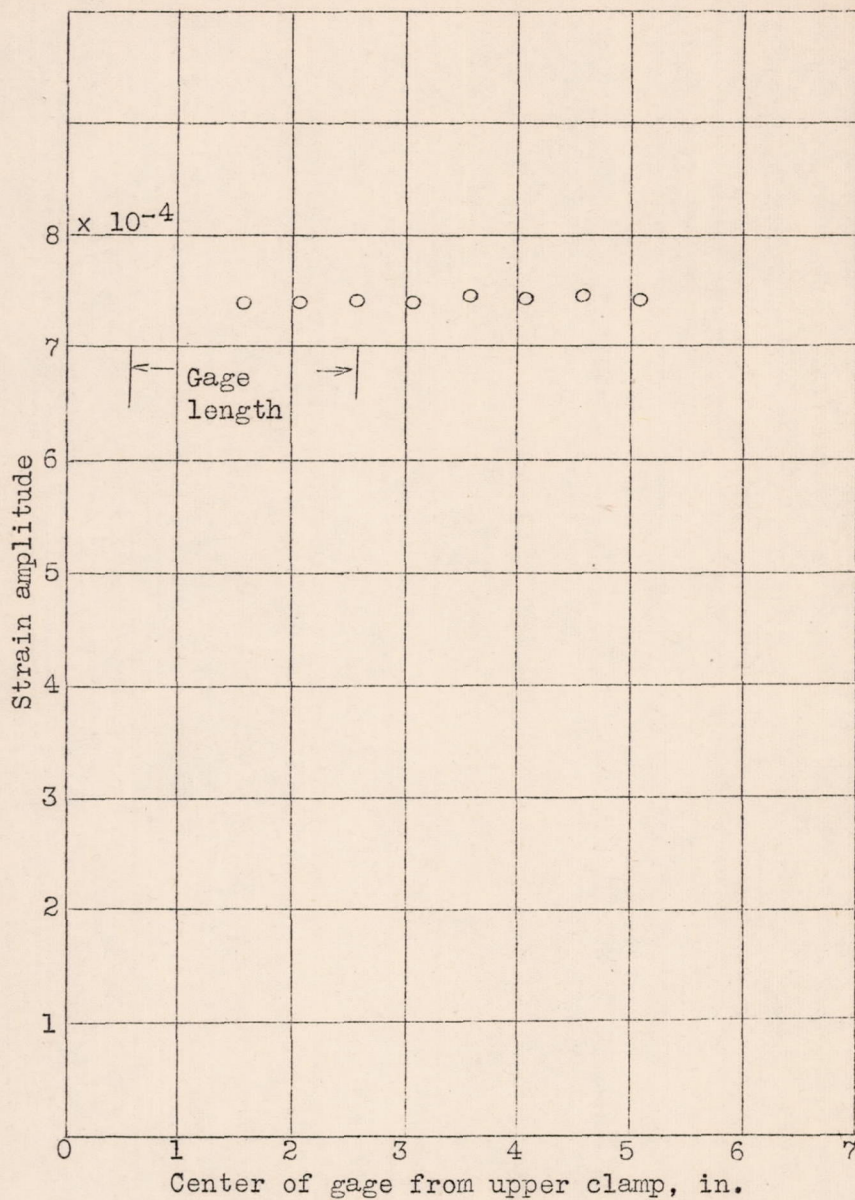Figure 11.- Strip, lamp bracket, bar, jack, jack assembly, and wiring arrangement for portable calibrator.

Fig. 11

Figure 12.- Strain against rise at cam for portable calibrator.

Figure 14.- Average strain over a 2-inch gage length
             at points along calibrating strip for
    intermediate cam setting. Strain amplitude, one-half
    excursion; frequency, 30 cycles per second.