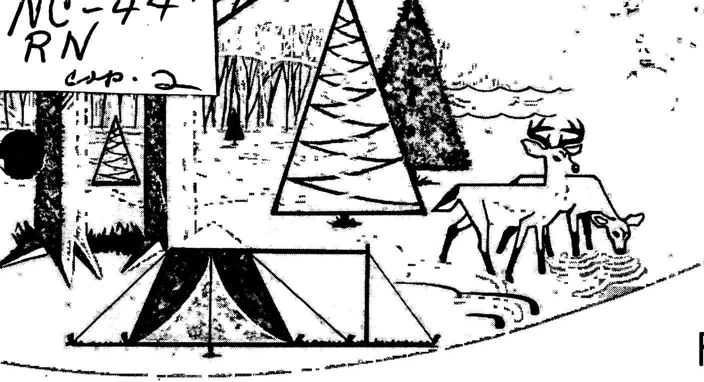

U. S. FOREST SERVICE

RESEARCH NOTE NC-44

NORTH CENTRAL FOREST EXPERIMENT STATION, FOREST SERVICE—U.S. DEPARTMENT OF AGRICULTURE
Folwell Avenue, St. Paul, Minnesota 55101

A Dual-Range Strain Gage Weighing Transducer Employing Automatic Switching

ABSTRACT.—Describes a dual-range strain gage transducer which has proven to be an excellent weight-sensing device for weighing trees and tree-length logs; discusses basic principles of the design and operation; and shows that a single transducer having two sensitivity ranges with automatic internal switching can sense weight with good repeatability and that one calibration curve serves the entire ambient temperature range in which it is used.

The Station's Forest Engineering Laboratory at Houghton, Mich., is engaged in research to promote the mechanization of woods harvesting operations. Current mechanization efforts involve the use of harvesting machines that handle full trees or tree-length logs and can perform several processing and handling operations.

To improve the design of these machines, information is needed on the weight and location of the center of gravity of the various forest tree species. To the author's knowledge, only one report has been published on the subject.[1]. The Laboratory is now cooperating with the Department of Forestry at Michigan Technological University on a study to obtain this type of information.

This Note reports on a unique transducer which is being used as the weighing device in the cooperative study[2].

The Problem

The basic problem was to design a transducer with adequate sensitivity for weighing full trees and tree-length logs which have a wide range of weights due to variability of tree size, form, and specific gravity within and between species. Furthermore, the transducer had to function with satisfactory repeatability (give the same readings for any given weight) and accuracy within tolerable limits over a temperature range of 10° to 90° F.

The expected maximum and minimum loads were established as 8,000 pounds and 100 pounds respectively. Because a single-range transducer designed for the maximum expected load would not be sensitive enough at the low end of the weight range, a transducer with two weight ranges, 0 to 2,000 and 2,000 to 8,000 pounds, was designed.

A dual-range transducer was chosen rather than two transducers (one for each weight range) to reduce rigging and hookup time in the field. Depending on the equipment being used, the hourly field costs could range from $20 to $30 per hour. Although the dual-range transducer is more complex than a single-range transducer, the combined cost of its construction and calibration was estimated to be only slightly more than that for two single-range transducers. The potential savings for in-the-field operation made the dual-range transducer a logical choice. The machining and assembly time for the transducer, including mounting the strain gages and wiring, was approximately 35 hours.

The Design

The dual-range transducer employs a tension rod with two different sized sections on which strain gages are mounted (fig. 1). Separating the two strain gage sections is an enlarged section that serves as the automatic switching device and controls the proportion of straining between the strain-gaged sections.

The transducer rod is housed in a steel capsule with a rigid surface on which the shoulder of the

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[1] *Keen, R. E. Weights and centres of gravity involved in handling pulpwood trees. Pulp Pap. Res. Inst. Can., Woodlands Res. Index 147, 93 p. 1963.*

[2] *Gary Viegelahn of the Engineering Mechanics Department, Michigan Technological University, made a number of helpful suggestions in the design of the transducer.*

rod comes to bear for loads greater than the maximum low-range load. The transducer rod and the containing capsule were made from the same material to insure equal thermal expansion. This point is critical if the transducer is used under varying ambient temperatures. If two different materials were used, the transducer calibration would be subject to change with temperature because of the differences in thermal expansion. Different materials having equal coefficients of thermal expansion are satisfactory.

The basic operational concept is that loads in the low-weight range are measured mainly in the small-diameter section (section A in fig. 1) and those in the high-weight range are measured mainly by the large-diameter section (section B). For any given load in the low-weight range, the small-diameter section elongates more than the larger section. This causes a greater change in resistance of the strain gages mounted on the small-diameter section and thereby a greater detectable change in the Wheatstone bridge output.

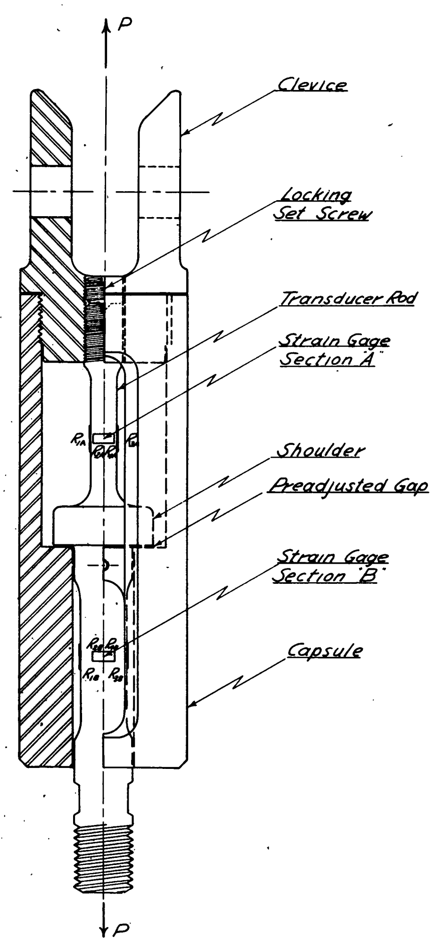

Figure 1.—Transducer assembly.

For loads in excess of the low-weight range, the transducer rod shoulder bottoms out within the transducer capsule and prevents the small-diameter section from being strained any further. Due to small imperfections in machining and alignment and the elasticity of the steel, bottoming out does not occur at a finite load but rather as a gradual transition between the two ranges (fig. 2).

The transducer capsule was designed so that the location of the zone of transition could be controlled by setting a predetermined gap between the bottom of the shoulder and the rigid bearing surface. This gap was set with a feeler-gage, and the transducer rod was locked in place with a set screw (fig. 1). This method for setting the predetermined gap may seem relatively crude; however, Section A of the transducer was sized so that it would be strained to only about one-third of the yield point at a gap setting of .0015 inch. Even if the gap were set at .003 inch (variations of .001 inch are detectable with feeler gages), the strain level would still be well below the yield point.

The gap was determined by making use of the following basic relationships between stress and strain for uniaxial loading.

$$\varepsilon \text{y.p.} = \sigma \text{y.p.} / E$$

where

ε y.p. = strain at the yield point,
σy.p. = stress at the yield point,
E = modulus of elasticity.

To prevent overstraining and hysteresis effects, a safety factor of three was used, thus the allowable strain level is given by:

$$\varepsilon \text{ allow} = \varepsilon \text{y.p.} / 3$$

The magnitude of the gap setting is obtained by multiplying the allowable strain by the gage length of Section A of the transducer rod.[3]

$$\text{Gap} = \varepsilon \text{ allow x Gage Length}$$

As previously indicated, it is *not* required that the gap be set such that the strain will be *exactly* one-third of the yield point strain, but only approximately that value. The important point is that once the approximate gap has been set, there *must* be a positive means to lock the transducer rod in the capsule so that the no-load gap does not change with handling. This is required to provide repeatability.

[3] *Gage length in this case is taken as the net length of the small-diameter section.*

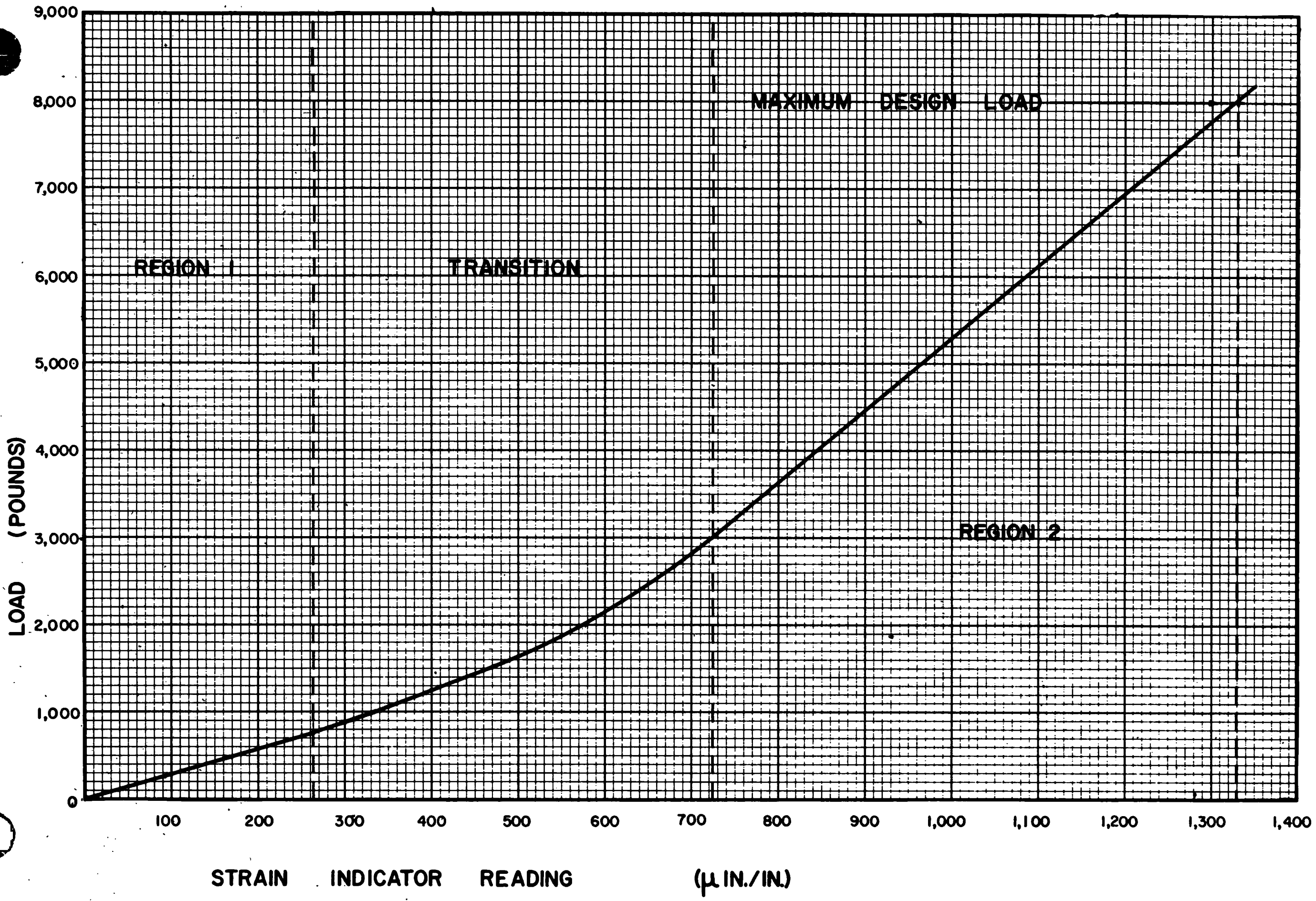

Figure 2.—Calibration curve for dual-range weighing transducer. The low-weight range falls within the area designated above as Region 1, the high-weight range in Region 2.

The diameter for each of the transducer rod sections is obtained by using the following formula,

$$d = 2\sqrt{\frac{P}{\pi E \varepsilon_{allow}}}$$

where

d = diameter of section (inches)
P = maximum design load of section (pounds).

Circuitry

Four 120-ohm SR-4 strain gages were mounted on each reduced diameter section of the transducer rod. Two of the gages in each section are mounted parallel to the longitudinal axis of the transducer rod and the other two are mounted at 90° to the longitudinal gages (Poisson arrangement). The longitudinal gages in Sections A and B are labeled R_{1A}, R_{3A}, and R_{1B} and R_{3B} respectively. Similarly the Poisson gages are R_{2A}, R_{4A}, and R_{2B} and R_{4B} (fig. 3). This gage arrangement provides for automatic temperature compensation and eliminates the effects of bending. Observation of the physical arrangement in the bridge circuit shows that the total output of the bridge is affected by the amount of axial strain in both Sections A and B.

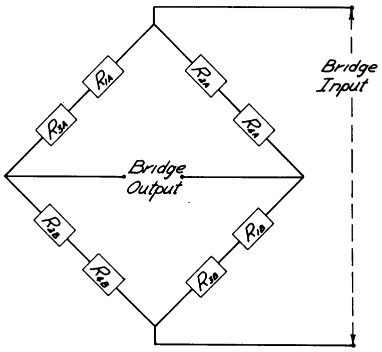

Figure 3.—Wheatstone bridge arrangement of strain gages.

The transducer was calibrated on a standard Tinus Olsen testing machine. The transducer output is linear in the low- and high-weight ranges and non-linear in the transition region (fig. 2). The chronology of the bridge output is as follows. In the low range both gage sections are strained and therefore both contribute to the bridge output—the largest contribution coming from the more heavily strained Section A. At the transition load there is a knee in the load-strain curve. During the transition stage the small-diameter section takes less of any additional load on the transducer. After complete bottoming out occurs, the gages in Section A are strained a constant amount since no further increases in load will be carried by the small-diameter section. The large-diameter section, however, continues to be strained with increasing loads, and all further changes in the bridge output are a result of straining the gages in Section B.

The change in strain per unit of load in the low-weight range is greater than the change in strain per unit of load in the high-weight range (fig. 2). For the calibration curve shown, the sensitivity in the low-weight range was 0.349 (μ inch/inch)/pound as compared to a sensitivity in the high-weight range of 0.144 (μ inch/inch)/pound;[4] the first being about 2.5 times more sensitive than the second. This transducer design therefore has greater accuracy for weights in the low range than would a transducer employing only a single diameter tension rod capable of measuring weights up to 8,000 pounds. If a single diameter rod (Section B) were used, the entire calibration curve would have a constant slope equal to that shown in the high-weight range (fig. 2).

The transducer was tested under laboratory controlled conditions in the temperature range of 16° to 65° F., and the same calibration curve as shown in figure 2 was obtained over this range of temperatures. This was expected, however, since the transducer was temperature compensated; and it was therefore concluded that one calibration curve would be satisfactory for the entire temperature range, 10° to 90° F., in which it would be used.

Typical results from the log weight study for which the transducer was designed are shown in figure 4. A battery-operated portable strain indicator was used to monitor the indicated strain readings. The individual components of the transducer are shown in figure 5.

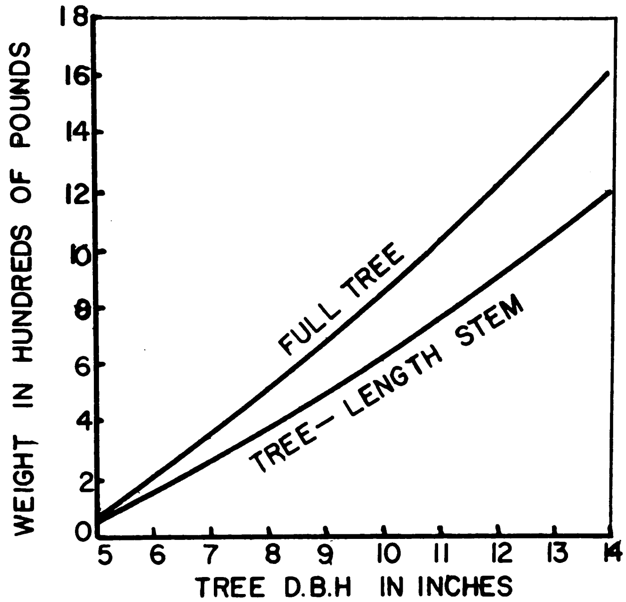

Figure 4.—Weight of full trees and tree-length stems versus tree DBH for 39 aspen trees.

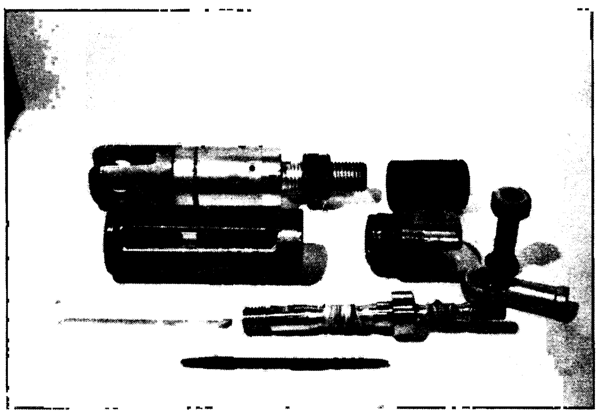

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Figure 5.—Transducer components.

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[4] *1 μ inch = 10^{-6} inches.*