A Tree-mounted LVDT Electronic Micrometer for Apple Fruit[1]

C. R. Willey and C. R. Unrath[2]
U. S. Department of Agriculture and North Carolina State University, Raleigh

Abstract. An easily constructed, lightweight LVDT electronic micrometer suitable for mounting in a tree for continuous monitoring of changes in apple fruit diameter is described. Four units were tested successfully under humid conditions on 'Delicious' apples during 90 days of the 1971 growing season.

LVDT refers to "linear variable differential transformer" or "linear variable displacement transducer," depending on the manufacture. Its use as an electronic displacement sensor for monitoring changes in plant stem diameter or fruit size has been described in several papers (1, 2, 3, 4, and others).

Changes in the diameter of intact apple fruit have been measured with an LVDT by mounting the sensor in a microscope stand supported by a metal frame (4). This note briefly describes another way of mounting an LVDT for in-the-field measurements on naturally positioned apple fruit.

Mounting procedure. The mounting unit (Fig. 1) is a simple frame constructed from non-rusting materials. The figure and accompanying parts description should adequately reveal the essential features of its construction. The unit is adjusted to fit various sized fruits by loosening the set screws in the aluminum bars (parts C and F) and sliding the parts along the parallel rods (part E). Fine adjustments are made with the calibration–adjustment screw (part G) which moves 0.63 mm (0.025 inches) per turn. The unit shown accomodates fruit up to 10 cm in diameter.

The LVDT we used was an ATC, Inc.,[3] model 6234-A-02-B01 which operated linearly within ± 0.05% over a ± 2.54 mm range. The plunger spring (24 ga phosphorous-bronze wire, part D) was cut to give a force of about 25 g on the plunger when in the operating position. To protect the LVDT coils from water, a silicone rubber cement[4] was applied over the ends of the LVDT except where the plunger rod (part D) entered.

The entire device, called an "electronic micrometer" (3), weighed 300 g.

The micrometer is held on a fruit (Fig. 2) by support rods (part A, Fig. 1). The rods are bent by hand to a shape that positions the micrometer over the fruit while most of each rod extends along the limb holding the fruit. The rods are taped to the limb. After position adjustments are completed, the fruit position is stabilized by stretching vinyl electrical tape across the micrometer on 4 sides of the fruit so that one edge of each piece of tape presses on the fruit. As the fruit grows, the tape stretches.

Field Test. Four electronic micrometers were attached to 'Delicious' fruits in a commercial orchard in Cleveland County, North Carolina from June 18 to Sept. 15, 1971. Two micrometers were placed in trees receiving over-tree crop cooling irrigations and 2 were in nonirrigated trees. The LVDT's were operated with a Model 6101-F[3] oscillator-demodulator and recorded on strip chart using procedures similar to those described by Tukey (4), except in this system the LVDT sensitivity was set at 0.254 mm/mv and the recorder range was 0 to 10 mv.

The curves of changes in fruit diameter obtained with the 4 units (Fig. 3) appear to be typical (5).

It was found that holding the apple in position in the micrometer with plastic electrical tape worked well. Most apples tilted slightly as they grew, but the diameter at the final sensor location was essential the same as that at the initial position. There was no change in fruit shape because of the pressure of either the LVDT plunger or the tape; only a lighter color at the points of contact.

Attachment of the micrometers directly to tree limbs held them sufficiently steady that storms and air blast sprayers did not disturb the operation of the equipment. The system required little maintenance: as the apples grew, the orchard owner adjusted the calibration-adjustment screw on each of the micrometers once or twice a week to keep the micrometer output within the range of the recorder.

The initial and final calibrations of the electronic micrometers (Table 1) reflect changes in calibration of both

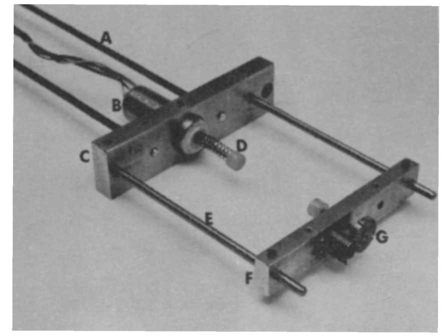

Fig. 1. LVDT electronic micrometer parts:
- A. Soft aluminum support rods (0.476 cm diam, 60 cm long, 2 rods).
- B. LVDT
- C. Aluminum block (11.4 x 3.17 x 1.27 cm).
- D. LVDT plunger.
- E. Stainless steel rod (0.48 cm diam, 16.5 cm long, 2 rods).
- F. Aluminum block (11.4 x 1.9 x 0.953 cm).
- G. Calibration - adjustment screw with position locking clip. The part consists of a 3.8-cm-long #4-40 stainless steel screw threaded through the aluminum block. A brass knob on one end of the screw facilitates turning and allows the screw to be locked in position with the clip formed from copper sheet metal. A 0.25-cm-diam nylon button is threaded on the other end.

Note: All rods and the LVDT are held in position with #10-24 stainless steel set screws.

Fig. 2. Tree mounted electronic micrometer assembly.

[1]Received for publication, July 24, 1972. Joint contribution from the Southern Branch, Soil and Water Conservation Research Division, ARS, USDA, and the Departments of Biological and Agricultural Engineering and Horticultural Sciences, North Carolina State University. Approved for publication as paper number 3827 in the Journal series of the North Carolina State University Agricultural Experiment Station, Raleigh, N. C. The use of trade names in this publication does not imply endorsement by the U. S. Department of Agriculture or the North Carolina Agricultural Experiment Station of the product names, nor criticism of similar ones not mentioned.

[2]Soil Scientist, U. S. Dept. of Agriculture, and Assistant Professor, Department of Horticultural Sciences, respectively.

[3]ATC, Inc., King of Prussia, Pa. Trade and company names are used to supply specific information. The U. S. Department of Agriculture neither guarantees nor warrants the standard of the product, and the use of this brand by the Department implies no approval of the product to the exclusion of others which may also be suitable.

[4]RTV - 102 silicone rubber, General Electric Co., Syracuse, N. Y.

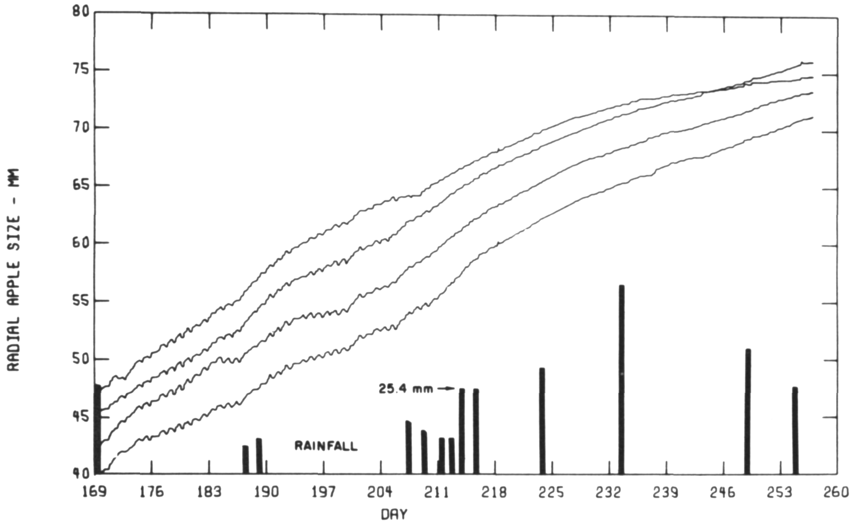

Fig. 3. Records of apple fruit diameter: the lower 2 curves are for fruit that received crop cooling irrigations on days 177 through 182 and on 5 scattered days between days 192 and 201; since the low-rate irrigations were infrequent, soil water conditions were essential the same for both the non-irrigated and irrigation-cooled plots.

Table 1. Field calibrations of electronic micrometers when installed on June 18, 1971 and when removed from the apples on Sept. 15, 1971, and a comparison of accumulated growth measured with the electronic micrometer and manual micrometer for each apple. Sensors 3 and 4 were each on an irrigation-cooled apple.

Measurement	Sensor 1	2	3	4
LVDT calibration (mm/mv)				
Installed	.252	.253	.252	.251
Removed	.231	.241	.239	.241
% Change	-8.3	-4.7	-5.2	-4.0
Apple size increases (mm)				
Electronic micrometer	29.9	26.8	30.8	30.5
Manual measurement	29.4	25.1	31.9	34.7
% Difference	+1.7	+6.8	-3.4	-12.1

the electronic micrometers and the oscillator-demodulators through which they operated. There was a slight loss of sensitivity, but all changes were less than 10%.

The total increases in apple diameters measured with the electronic micrometers and those determined from manual measurements of the apple dimension at the beginning and end of the test (Table 1) differed no more than 12%.

The success of this one-season test indicates that reasonably accurate, season-long records of apple size changes can be obtained using the electronic micrometer and mounting procedure that have been described.

Literature Cited

1. Klepper, B., V. D. Browning, and H. M. Taylor. 1971. Stem diameter in relation to plant water status. *Plant Physiol.* 48:683-685.
2. Namken, L. N., J. F. Bartholic, and J. R. Runkles. 1969. Monitoring cotton plant stem radius as an indication of water stress. *Agron. J.* 61:891-893.
3. Splinter, W. E. 1969. Electronic micrometer continuously monitors plant stem diameter. *Amer. Soc. Agr. Eng. J.* 50:220-221.
4. Tukey, L. D. 1964. A linear electronic device for continuous measurement and recording of fruit enlargement and contraction. *Amer. Soc. Hort. Sci.* 84:653-660.
5. ———. 1970. The growth and development of apple fruits with special reference to golden delicious. *Pennsylvania Packer* 35:5-12.

A Simple Method for Controlled Introduction of Fresh Air into Experimental Cold Storage Rooms[1]

E. Chalutz, G. Felsenstein, and J. Waks
Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel

Abstract. **An inexpensive method for accurate control and measurement of fresh air introduction into experimental storage rooms is described.**

Introduction of fresh air into cold storage rooms for perishable commodities is intended to avoid accumulation of volatiles that may adversely affect the quality of the stored produce. Although this is a common practice with some commodities, notably citrus fruit, little information has been available on the optimal rates for the introduction of fresh air.

For commercial precooling, cold storage and transport of citrus and other fruits, fresh air is introduced at rates ranging from 1 to 6 exchanges of room vol/hr based on empty room vol (H.F. Th. Meffert, The Sprenger Inst. Wageningen, Holland; V. Gessel, TEMPCO, Alhambra, California and S. Biron, Citrus Marketing Board of Israel, Tel Aviv, personal communications). These rates equal approx 5 to 60 m^3/ton-hr of produce. The accumulation of CO_2 inside the room is often used as a criterion for determining the rate of fresh air introduction. Since ambient temp and relative humidity are rarely similar to those inside, introduction of fresh air at such high and possibly excessive rates may increase the refrigeration-heating load by a large factor. In addition, difficulties in maintaining the desired temp and relative humidity are likely to result. Thus, the environment inside storage rooms may be nonoptimal and cost of operation may be excessive.

When introduction of fresh air is used to avoid accumulation of undesired volatiles, determination of the min rates required would obviously be valuable. In small-scale experiments where fruit are placed in small containers, min rates required can be studied. However, data obtained in such experiments may not be directly applicable commercially, since factors, such as packaging, stacking and nonuniform air circulation, can not be evaluated in small scale experiments. Therefore, before min rates of fresh air introduction can be recommended to the industry,

[1]Received for publication December 13, 1972. Contribution from the Agricultural Research Organization, The Volcani Center, Bet Dagan 50200, Israel. 1972 Series, No. 2238-E. The help of Mr. Y. Schwarz in designing the disc system is hereby acknowledged.