THE USE OF A COMPUTER WITH AN INSTRON FOR TEXTURAL MEASUREMENTS[3]

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(Manuscript received July 19, 1981; accepted October 1, 1982)

ABSTRACT

A minicomputer was interfaced with an Instron so that force/deformation tests could be performed and analyzed automatically. The equipment eliminates time consuming measurements and transcription of data from recorder charts. The data extracted include force, deformation, slope and area variables not previously reported as well as the usual texture profile parameters. Procedures and analyses are illustrated by texture profile measurement of apple tissue. Comparison of visually and computer selected force at failure indicate satisfactory computer identification of the Texture Profile "fracturability" parameter, the parameter most difficult to interpret for apples.

INTRODUCTION

Instron universal testing machines and similar instruments are widely used to measure mechanical properties of foods, including "texture profile" parameters (Voisey 1971; Szczesniak 1973; Breene 1975). The instruments normally provide a force/time plot from which a force/deformation (F/D) plot is derived and from which data are taken. Taking the data from the plots is time consuming, requiring measurement of the various distances, slopes and areas with a ruler and planimeter. If slopes are of interest, determining linear limits and accurately measuring the slopes of short sections of the curve are difficult. In addition, with the use of plots, recorder response speed may be a limiting factor (Voisey and Kloek 1975).

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Journal of Texture Studies 13 (1982) 413-422. *All Rights Reserved.*

Computer attachments providing automatic readout of selected force-distance parameters are available. The Instron computer system is not suitable for texture profile work (Voisey, personal correspondence). Bourne *et al.* (1978) suggested that direct selection of data points by computer could lead to serious errors in interpreting texture profiles because of variations among curve shapes. They used a digitizer with which the operator marks the desired data points and triggers their entry into the computer. The curve is then traced with the cursor, entering the curve as pairs of X-Y coordinates for calculating areas. This operation still relies on F/D plots, is time-consuming and is dependent on manual skill and individual interpretation.

This report describes the methodology we have developed to interface an Instron with a minicomputer and its successful use for measuring F/D parameters. The tests performed by the system involved measuring and recording the load cell output signal, controlling movement of the Instron crosshead at two speeds and two directions, and automatically extracting numerous data from the resulting F/D curves. The system has been used for three basic types of F/D tests: (1) texture-profile-type compression tests, (2) a modified Magness-Taylor firmness test which involves puncturing to a specified depth and extracting yield and maximum forces and the respective deformations, and (3) a snap test which involves detecting break force and deformation. A single-cycle modification of the texture profile is described in detail herein because it illustrates determination of force at a specified depth, maximum force, and break force, as well as other force, slope, area, and deformation variables.

EXPERIMENTAL

Computer Programming

The programs to control the Instron and to take the data were written in BASIC with machine language subroutines to operate the analog-to-digital (A/D) converter and to control the Instron. The programs for performing the measurements supply operator cues and can provide, immediately after each test, either the maximum force or the force at a prespecified deformation. Separate analysis programs were written for each type of test to extract and output the desired data for statistical analyses. Programs are available upon request.

Instrumentation

An Instron Model TM (English units) was interfaced with an existing Data General Nova 1200 minicomputer; however, the principles of instrumentation and programming which we describe are applicable to other minicomputers, such as personal computers.

Six pairs of wires are required for connection and operation: one pair connects the load cell to the computer, two operate the computer from a teletype terminal at the Instron site, two drive the display screen, and one enables the computer to control the Instron. The Instron load cell strain gauge bridge excitation voltage is 1.6 volts, output is approximately 70 μV/N. A Datel AM-201 instrumentation amplifier amplifies the bridge output signal by 1000. The amplifier is followed by a low pass resistive capacitive filter and buffer amplifier to reduce electronic noise. The signal then passes to the differential front-end of a 14 bit A/D converter on the computer.

A contact closure which could be controlled by the computer was substituted for the Instron's maximum load switch (Fig. 1). Opening and closing the maximum load switch controls crosshead motion. For example, when the minimum extension switch and dial are set to run the crosshead down and the maximum load switch and dial are set to run it up, the conflicting conditions prevent movement; opening the maximum load switch cancels the command to move up and permits the crosshead to start down. All movement except stop and A speed up are controlled by the Instron extension limit switch settings. The Instron gears are used for selecting crosshead A and B speeds. The gauge length and return dials are used for setting gross limits on downward and upward movement as a safety precaution. The extension cycle dials establish the upper and lower ends of the test stroke in conjunction with the cycle control panel (plug panel) and computer commands. The cycle control panel permits use of both A and B speeds on down and/or up strokes. The usefulness of the two speed feature depends on the test being performed. The A speed at 25.4 mm/min is used for both the down and up strokes of our texture profiles tests. The B speed at 254. mm/min is used to automatically position the probe at the beginning of each test and to remove it after the test to facilitate removal of the spent specimen and placement of the next specimen.

The basis of data collection and crosshead movement is time. A crystal clock external to the computer furnishes a pulse every 0.06 s which triggers the computer to take 700 A/D readings of the load cell signal at 50 μs/reading. The readings are averaged together to form one data point. At a crosshead speed of 25.4 mm/min, each data point represents 0.0254 mm. This time counting system is also the basis of the computer control of the crosshead; for example, the texture profile programs are written so that movement reverses 0.295 min after contact with the specimen. With the time count method, changing test speeds simply requires changing Instron gears and the times in the program.

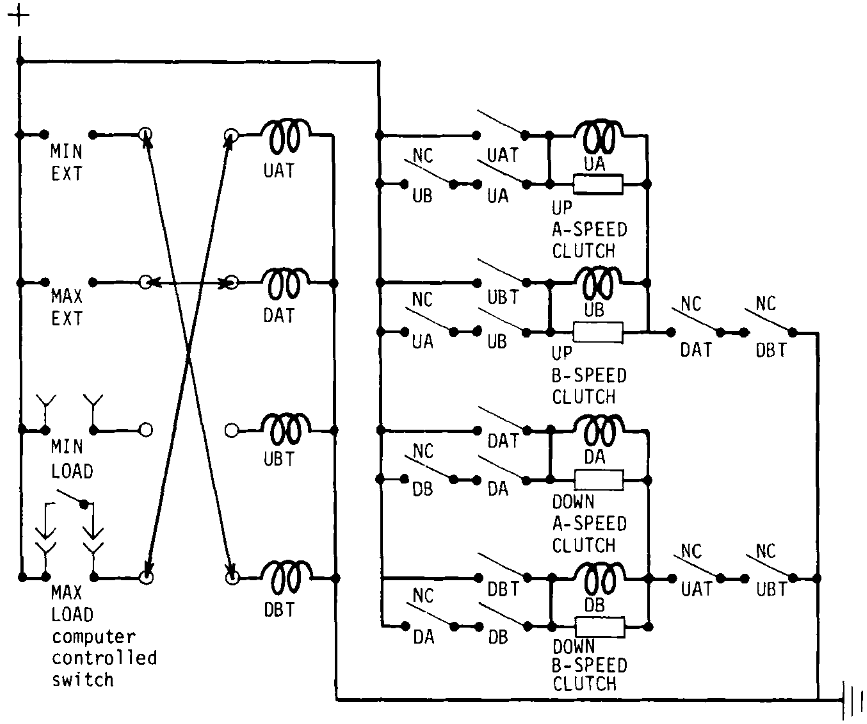

FIG. 1. SIMPLIFIED SCHEMATIC OF INSTRON UNIVERSAL TESTING INSTRUMENT CROSSHEAD CONTROLS

(Gauge, return, brake, manual switches, and relays not shown). Abbreviations follow Instron manual. Open circles indicate plugs and arrows indicate jumper wires.

A display screen driven by the computer allows the operator to observe the F/D curve after the test. It is possible to program the system to display the developing F/D curve as the test progresses but at a cost in accuracy—fewer A/D readings can be made.

The Instron is calibrated by measuring the difference in load cell output with no weight and with a known weight. For force measurements, the difference is divided by the force exerted by the calibration weight to calculate A/D units per newton (N) (ASTM 1980). For weight measurements, the difference is divided by the calibration weight to determine A/D units per gram. The load cell is automatically tared at the start of each F/D measurement. The weighing capacity of the load cell can be utilized for weighing specimens. A feature can be included in the program to record specimen weights along with the F/D data, as we do in the Magness-Taylor test of whole fruit firmness.

Texture Profile Tests

To illustrate the operation, data collection, and data analysis potential of the Instron/computer, a single-cycle texture-profile measurement (Breene 1975) will be described. A 10 mm thick cylinder of fruit tissue is compressed to 2.5 mm at 25.4 mm/min (75% compression in 0.295 min) then the crosshead moves up at the same speed for 2.6 mm of rebound (Fig. 2).

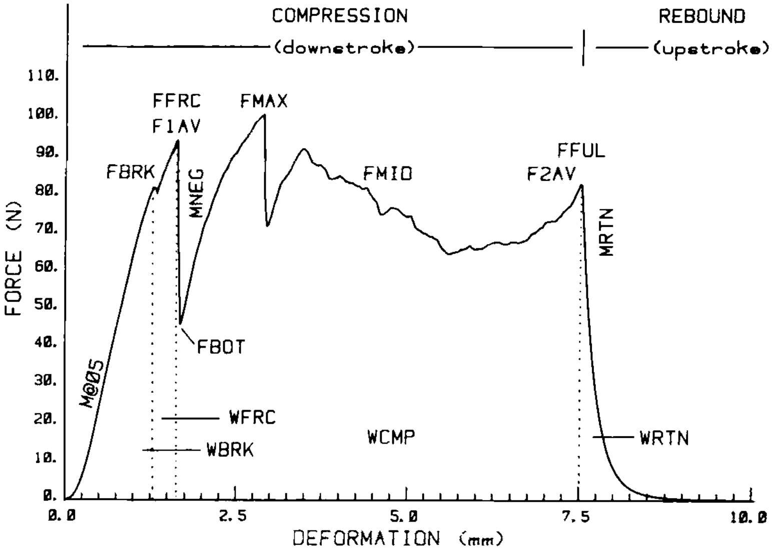

FIG. 2. FORCE/DEFORMATION CURVE FOR GOLDEN DELICIOUS APPLE SPECIMEN ILLUSTRATING SELECTED VARIABLES

Areas prior to 7.5 mm deformation are cumulative. Acronyms are defined in Table 1.

The compression plate (probe) mounted under the crosshead is positioned 23.7 mm above the load cell surface, using a metal block as a feeler gauge. The extension minimum dial is set at 0.00 and the extension maximum dial is set at 13.2 mm. The Instron's cycle control jacks are connected as follows: extension minimum to down B, extension maximum to down A, and load maximum to up A (computer controlled) (Fig. 1). This allows four speed X direction combinations. The load cell is then calibrated. Full scale force for the display is programmed at 111 N for apples and the contact threshold value is programmed as 0.1% full scale.

At the starting position, the probe is 23.7 mm above the load cell to allow space for placing the specimen. The crosshead moves at down B speed (fast) to 11 mm above the load cell surface, where it is switched to down speed A (test speed). The computer then takes 7000 readings (10 data points) to determine the zero force signal to tare the load cell. It then takes readings and compares each to the contact threshold value to detect contact with the specimen. When contact is made, the computer allows the crosshead to continue at down A speed for 7.5 mm, then switches to up A speed (computer controlled) and continues to record data while the probe is moved upward for 2.6 mm. At that point, data collection ceases and the probe is returned to the starting position at up B speed.

The force at 7.5 mm is printed on the teletype, the F/D curve is displayed, and the operator is prompted to signal the computer either to record the curve on magnetic tape or to repeat the measurement.

Data Extraction

Numerous data are extracted from our texture profile curves, including some not generally taken at other laboratories (see Table 1 and Fig. 2). A first derivative curve is calculated with the formula:

$$M_i = \frac{\dfrac{(F_{i+2} + F_{i+3})}{2} - \dfrac{(F_{i-3} + F_{i-2})}{2}}{0.127\ \text{mm}}$$

where M_i = slope at data point i, F_{i-3} is force at data point i-3, etc. The derivative curve is used to define all slopes and to identify those points defined by derivatives (slopes) in Table 1, e.g. FBRK and FFRC. If the slope of the curve over a broader distance is desired, it can be similarly calculated by simply changing the derivative program. Deformations are identified by data point number (of the 400 data recorded) and converted to mm. To avoid confusion, deformations during rebound are expressed as distance from crosshead reversal plus distance from the contact point to crosshead reversal; thus, our termination point is written 10.1 mm (2.6 mm + 7.5 mm).

DISCUSSION

Bourne *et al.* (1978) cautioned that serious errors can arise if data from F/D curves are extracted by computer without interpretation of the curves by an experienced operator. The most difficult feature to identify is the "fracturability" (Bourne 1978), initially referred to as "brittleness" (Friedman *et al.* 1963). To test the accuracy of the definition used for computer identification of this peak (defined as F and D at first zero derivative), we visually identified the point of rupture (defined as the top of the abrupt drop marking rupture on the F/D curve) from 140 Golden Delicious and 144 York Imperial apples. This was done by displaying each curve on a graphics terminal with a zoom feature and a moveable cursor so that each data point could be seen and identified. Visually selected force and deformation are labelled FTOP and DTOP, respectively.

Table 1. Definitions of variables extracted from texture profile (force/deformation) curves, progressing from contact through crosshead reversal at 7.5 mm to 2.6 mm of rebound

Contact	Contact threshold = full scale force × 0.001 = 0.11 N for apples
M@05	Slope at 0.5 mm, apparent elasticity = M@05/128.46 mm^2
MBRK	Maximum slope to breakpoint, max. slope between Contact and first zero derivative, apparent elasticity = MBRK/128.46 mm^2
DMBK	Deformation at MBRK
FBRK	Force at first break in curve or breakpoint, "yield force" (Mohsenin *et al.* 1965), force where slope first drops below 0.5 MBRK
DBRK	Break point, "yield point" (Mohsenin *et al.* 1965), deformation at FBRK
WBRK	Work to break point, area under curve to DBRK
FFRC	Force at failure or rupture, "fracturability" (Szczesniak 1975), maximum force to first zero derivative
DFRC	Deformation to FFRC
WFRC	Work to failure or rupture, area under curve to DFRC
FTOP	Visually selected rupture force, force at top of abrupt drop
DTOP	Visually selected rupture deformation, D at FTOP
F1AV	Average force of first peak, mean force DBRK to (DBRK + 1.0 mm)
MSDV	Standard deviation of slope from DBRK to (DBRK + 1.0 mm)
FMAX	Maximum force to 5.0 mm, usually = FFRC
DFMX	Deformation at FMAX
MNEG	Slope of abrupt drop after rupture, maximum negative slope DFRC to 7.5 mm
DMNG	Deformation at MNEG
FBOT	Force at bottom of abrupt drop, minimun force between DFRC and (DFRC + 0.76 mm)
DBOT	Deformation at FBOT
FMID	Mean force midway between DBRK and 7.5 mm for a distance of 1.0 mm
F2AV	Average force of final peak, mean force from 6.5 mm to 7.5 mm
FFUL	Force at full compression, "hardness" (Friedman *et al.* 1963), force at 7.5 mm
7.5 mm	Crosshead reversal, end of "full" compression stroke of 75% initial height
WCMP	Work to compress, area under curve to 7.5 mm
MRTN	Maximum slope during crosshead return stroke, maximum slope of rebound curve
DMRN	Deformation at MRTN (7.5 mm + distance past crosshead reversal)
WRTN	Work returned on rebound, area under curve from 7.5 mm to 10.1 mm
10.1 mm	Termination (7.5 mm compression plus 2.6 mm rebound)

The computer extracted FFRC data were regressed on the visually selected FTOP data (Fig. 3). The regression equations (Table 2) showed that the computer satisfactorily measured the fracturablility force. In addition, F1AV and FMAX were compared with FTOP (Table 2). Despite high correlations, F1AV was not a satisfactory measure of fracturability, as the slopes differed signifcantly from unity. FMAX differed greatly from fracturability in Yorks, the difference indicating strong secondary peaks in that cultivar.

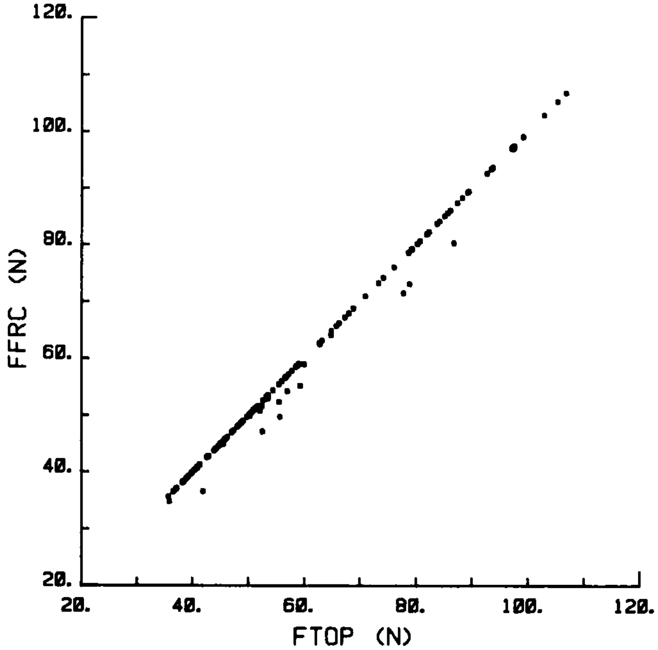

FIG. 3. COMPARISON OF VISUALLY SELECTED FRACTURABILITY FORCE FTOP AND COMPUTER SELECTED FRACTURABILITY FORCE FFRC FOR 140 GOLDEN DELICIOUS APPLES (TABLE 2).

Although the deformation at the fracturability force is not usually reported in texture profile analyses, we compared values for this parameter determined using the visual (DTOP) and computer (DFRC) definitions for fracturability (Table 1). The regressions (Table 2, Fig. 4) indicated that the definition used in computer extraction of location of the fracturability peak was not satisfactory in all cases. Failure was often identified as being at smaller deformations by the computer than by visual selection (Fig. 4). Inspection of the curves indicated that the low correlation for Golden Delicious was partly due to relatively broad flat peaks for some of the riper apples. The very narrow range of possible values tended to magnify the significance of slight shifts in location between the visually and the computer selected points. As expected, the location of the maximum force, DFMX, was not necessarily the same as the fracturability peak. If deformation at rupture were of interest, the computer definition should be modified to better identify failure, perhaps using beginning of negative slope over a specified force drop as a criterion.

Table 2. Comparisons among definitions of the fracturability peak, regressions of computer selected data on visually selected data

Dependent	Independent	Golden Delicious			York Imperial		
Variable(Y)	Variable(X)	b_o	b_1	r^2	b_o	b_1	r^2
FFRC	FTOP	-0.132	0.996	0.995	-0.000	1.000	1.000
F1AV	FTOP	5.862	0.784	0.959	5.271	0.855	0.849
FMAX	FTOP	-2.012	1.048	0.992	4.222	1.069	0.613
DFRC	DTOP	0.039	0.719	0.611	0.052	0.955	0.976

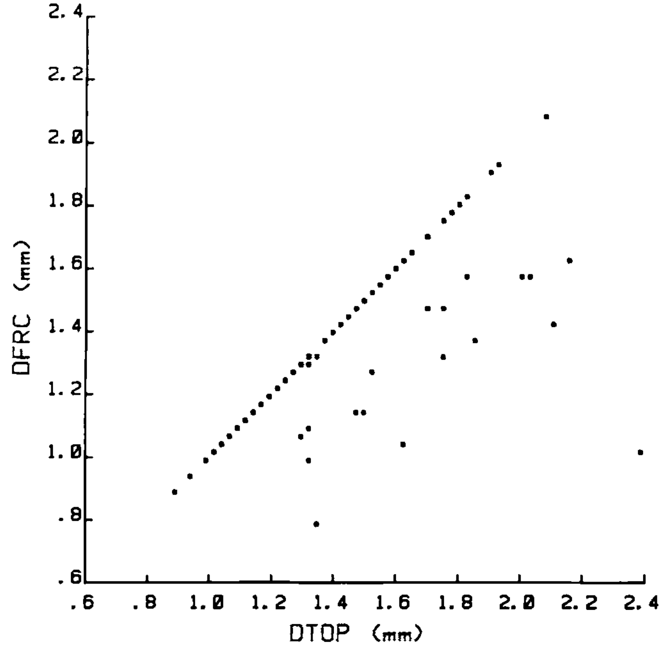

FIG. 4. COMPARISON OF VISUALLY AND COMPUTER SELECTED LOCATIONS OF FRACTURABILITY PEAK, DTOP AND DFRC, RESPECTIVELY, FOR 140 GOLDEN DELICIOUS APPLE SPECIMENS (TABLE 2).

Defining other events, such as the break or yield point (DBRK and FBRK), should present less difficulty than defining fracturability.

CONCLUSIONS

We have found that a computer-Instron assembly can be used very successfully to run texture profile and other force/deformation tests with an Instron and to collect and extract the data. The use of a computer makes practical the measurement of large numbers of samples and large numbers of variables. Satisfactory automatic extraction of data depends on thorough examination of sample curves and careful definition of the parameters to be measured. The various features can be defined by appropriate qualifying terms such as change in slope, deformation "windows," maximum and minimum forces, etc. Separate analysis programs will probably be necessary for foods exhibiting extremely different curve shapes.

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