C S A E   S C G R

Paper No. 89-6010

AN ASAE/CSAE MEETING PRESENTATION

Canadian Society of Agricultural Engineering

ROLL-2: RAPID SINGLE KERNEL WHEAT CHARACTERIZATION

by

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Written for presentation at the 1989 International Summer Meeting jointly sponsored by the AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS and the CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING

Quebec Municipal Convention Centre
Quebec, PQ, Canada
June 25-28, 1989

SUMMARY:

A crushing device was developed to determine crushing, moisture, and size characteristics of single wheat kernels at a rate of approximately 180 kernels per minute. Hardness of single kernels was measured and corrected for the effects of moisture and size interactions. The instrument was evaluated to determine its potential for classification of wheat and inclusion in the official grain inspection process.

KEYWORDS:

Wheat, Hardness, Instrumentation, and Physical Properties

American Society of Agricultural Engineers

St. Joseph, MI 49085-9659 USA

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Product uniformity is a widely used measure of quality and a legitimate factor in grain grade determinations. Uniformity, when measured or known, can be defined by standards that lead to improvements in marketing. Product uniformity is the basis for the need to identify the class of individual kernels when the grain is graded. Grain inspectors have difficulty grading wheat when different varieties have similar appearances as in the case of red wheats.

Soft wheat flour is milled differently from hard wheat (Neel and Hoseney 1984). Bulk hardness measurements are useful for determining whether a wheat sample is hard or soft, and they provide guidance for tempering and milling procedures. However, bulk hardness measurements do not provide information on whether or not wheats of different hardness have been blended. Millers blend and successfully mill wheats of different hardness. However, the prediction of an optimum milling method or expected milling yield requires more information than is supplied by bulk hardness alone. Knowledge of the within-sample variability of hardness (kernel to kernel) may be used to enhance milling efficiency.

Single kernel hardness measurements were obtained from force-deformation curves created by crushing a wheat kernel between two surfaces that move closer together over time. Force was represented by a voltage signal while kernel deformation was represented by time. Characteristics of the force-deformation curve that are representative of hardness include slope values or force change as a result of a specific change in kernel deformation (time), specific peak force values that occur at intervals during deformation, and areas under the curve between specific deformation values. Earlier single kernel hardness studies (Lai et al., 1985) showed that ratios of front slope to back slope about the first peak were good indicators of hardness. In single kernel compression instrument measurements (Pomeranz et al., 1988), two hardness parameters were used. One was based on a first peak force, the other on a specific area determination from a summation of the absolute slope values over a specified time interval. In the use of the first version of a rotor-crescent device (Martin et al., 1987), the slope values were shown to be better indicators of hardness than peak values. The objective of this paper is to describe the development of an experimental single kernel wheat

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characterization system.

DEVELOPMENT OF ROLL-2

A crushing device, Roll-2 (Fig. 1) was developed to determine hardness and other characteristics of single wheat kernels. The determinations include crushing, moisture, and size characteristics at a rate of approximately 180 kernels per minute. Single wheat kernels were crushed as they pass through a wedge shaped cavity between a smooth crescent surface and a coarse toothed rotor. The crescent was a lever supported by a load cell that measured a force vector from the crushing action. The rotor was electrically insulated so that a conductivity profile could be used to determine kernel moisture. Kernel size was measured using the time that a kernel exerts force on the crescent. Data acquisition was automatic and controlled by computer software that responded to the force and conductivity data from an analog to digital (A/D) converter. The software collected data from a prescribed number of kernels, processed the data, and stored machine data summary parameters for each kernel. The single kernel summary parameters required further processing for conversion to hardness, moisture, and size measurements. Total sample throughput time ranged between 2.0 and 2.5 minutes for a 300 kernel sample (about 10 g).

Single Kernel Feeder

A precision kernel feeder (Fig. 2) was designed to deliver individual kernels to the instrument from a bulk sample contained in a horizontal drum (8.5 cm dia. by 5 cm) that rotated at 30 rpm. Individual kernels were oriented and conveyed toward a face plate as they moved and tumbled in and along a spiral groove inside the drum. A U-shaped groove intercepted a kernel by holding it in the groove with vacuum from one of six small pickup holes in the bottom of the groove. The intercepted kernel was elevated by the drum while other kernels fell or slipped downward inside the drum. The face plate has an intercepting groove inside the drum which formed an enclosed chamber. The elevated kernel was carried into the chamber where it was dropped by vacuum release with constant orientation. The falling kernel was guided by the chamber into an angled hole that lead into the rotor-crescent cavity.

Crushing Device

A brass rotor (Fig. 3) was driven by a 186 W direct-current gear motor using an electronic speed controller. The stainless steel crescent was supported by a linear variable differential transformer load cell (Daytronic 152A-100, 100 lb. rated load range) connected to a Schaevitz excitation and signal conditioner. The calibration setting for the load cell was 108.3 N per volt which translated to an A/D converter (12 bit resolution, 10 volts full scale) output of 0.2644 N per A/D count.

The crescent was a lever designed to have a two-to-one mechanical advantage between the point of most frequent kernel contact and the point of kernel exit. This crescent design mechanically amplified the initial contact force to enhance signal detection and increase sensitivity at the initial fracture stage.

The rotor-crescent cavity was a non-linear wedge with a 4.37 mm gap (to accept large white and durum kernels) at the entrance. The gap decreased through a 93 degree crescent arc to 0.508 mm at the exit (measurements are tooth tip to crescent). With the rotor operated at 120 rpm, kernels were deformed at a rate of approximately 30 mm/s, nearly the same as that used in a previous single kernel hardness study (Pomeranz et al., 1988).

The by-products generated during kernel crushing, heat from friction on the crescent, and dust from crushed kernels, were controlled by air flow. A fan (60 cfm) creates a negative pressure inside the machine that moved air to cool the crescent and control air-borne dust particles.

Data Acquisition

A multifunction high speed analog/digital I/O expansion board (MetraByte Dash-16) mounted in an expansion slot of an IBM PC/AT compatible personal computer was used for data acquisition. The data acquisition cycle began with the A/D system monitoring the force signal to detect kernel entry. Upon kernel detection, the system initiated rapid acquisition of conductance and force data at 0.25 ms intervals and stored the data in computer memory. Data acquisition continued for 125 ms with actual crushing time ranging between 50 and 100 ms. At a kernel throughput rate of three per second, 208 ms of CPU time was available for data processing, storing and initializing of the system for the next kernel.

Machine Data Summary Parameters

The single kernel crushing system generated approximately 1000 conductance and force measurements for each kernel processed. Storing all machine data points for each kernel was incompatible with the initial PC computer capacities. Consequently, a method for condensing individual kernel measurements to a small number of summary parameters was developed. As a starting point for Roll-2 evaluation, an initial data set was collected using samples of soft and hard wheat varieties at about 12.5% moisture content. Slope values (DY), measured in A/D counts across each 0.25 ms interval, were calculated from the machine data representing the force profile. A frequency distribution of the DY counts was made to determine the relationship between sample hardness and DY counts. The machine data summary (Table 1) parameters were selected after the analysis of the initial data set.

Moisture

Both force and conductivity measurements (Fig. 4) were used to determine the moisture of a single wheat kernel. A regulated -90 volt dc source (Analog Modules model 521, Longwood, FL.) was connected to the rotor through a 1 megohm resistor. Conductance ranged between 0.002 and 2.0 microsiemen for single kernel moisture between 10 and 17 % respectively. The conductance signal was coupled through a 0.05 microfarad capacitor to a log ratio amplifier which provided an output signal proportional to log (conductance) - log (force) or log (conductance/force). The output signal, 1.5 - 8.5 V, was connected to the A/D converter.

A moisture calibration was obtained using 3 varieties each of hard red spring (HRS), hard red winter (HRW), and soft red winter (SRW) wheats at 5 different moisture levels in the range between 10 and 17 %. Moisture determinations for all wheats at each moisture level were made by the oven method for ground wheat using a Wiley mill and a #20 mesh screen. Moisture calibration data were also used to determine the effect of moisture on hardness parameters and to establish moisture correction constants. Moisture determinations allow hardness measurements to be corrected to a constant moisture basis.

Size

The diameter of a kernel determines the point in the cavity (Fig. 3) where initial force contact occurred between the crescent, kernel and rotor. Large kernels make contact sooner and pass through a greater contact arc than small kernels. For constant rotor speed and zero slip, the contact arc was proportional to contact time which was proportional to rotor-crescent gap and hence kernel size.

A statistical size calibration was developed using the number of time intervals that a kernel exerts force on the crescent (number of positive DY values in force signal). A size algorithm, developed from 253 samples representing the 5 major wheat classes, was used for hardness measurement corrections relating to kernel size. Kernel size was determined by kernel weight of 3 different sizes segregated by sieving. Average kernel weight of each sieved fraction was determined before crushing. If the sieved fraction was less than 16 kernels, the fraction was omitted in the size calibration.

Hardness

Hardness was determined from the force profile stored in computer memory by the A/D converter. At the end of data acquisition from a kernel, the computer and processing software made a frequency summation of specific slope values measured across time intervals of the A/D converter (0.25 ms) and stored summary parameters in memory. After all kernels in a sample were crushed, the summary parameters were further processed by the computer and software to calculate hardness values corrected for moisture and size for each kernel.

A wheat hardness reference sample set (NWHS), supplied by the Federal Grain Inspection Service for instrument calibrations in the National Wheat Hardness Study (Wishna, 1989), was used for hardness calibration and determination of the optimum size correction coefficients. The NWHS set included 17 samples from five major wheat classes, HRW, HRS, SRW, white wheat (WW), and durum. There were three NWHS reference set runs made over a period of four months, each with samples equilibrated to a different moisture content. The first run in March 1988 was before processing 716 samples of HRW and HRS wheat, the second run was in May before processing 253 samples representing the 5 major wheat classes (McGaughey, Speirs, and Martin, 1989), and the third run was in July after processing 1200 samples from the 1988 National Wheat Hardness Study (Wishna, 1989).

For Roll-2 hardness calibration, the scaling constants (slope and intercept) were determined so that the 5 soft and 10 hard wheat sample average hardness values were 25 and 75 respectively. Overlap between hard and soft wheat hardness values may be represented by the absolute difference of the hard and soft means divided by the sum of the respective standard deviations. This ratio represents the number or multiple of standard deviations where overlap occurs between hard and soft wheat hardness values in a normal distribution and was used as an index of classing efficiency. The larger the index, the greater the classing efficiency and an index value of three represents very little overlap.

Optimum size correction constants were determined by selecting the values that produce the greatest classing efficiency (least overlap) between soft and hard wheat varieties in the NWHS reference set. Selection was made after several iterative trials starting with no size correction and increasing the size correction until a maximum classing efficiency was observed.

A method which improves both the classing efficiency and stability of Roll-2 was developed using two hardness functions in a strategy to reduce kernel to kernel variability. The mean of both hardness values over all the kernels in a sample was calculated. Then for each kernel, the hardness function giving the value closest to this mean was used as the final score. This reduced the kernel to kernel variation. The distinction between hard and soft wheat was retained however, because each hardness algorithm independently differentiated hard and soft wheat in nearly equal manner.

RESULTS AND DISCUSSION

Crushing Profiles

Soft wheats (Fig. 5) produced smooth low profiles with "flowing" or mild slopes as kernels disintegrated into a multitude of small particles. Hard wheats (Fig. 6) produced jagged profiles with multiple peaks and sharper slopes as kernels fractured into smaller and smaller particles. The inset in Figs. 5 and 6 show the average profile and the profile ± one s.d. for 320 kernels of the same variety or class.

The frequency distribution of the DY counts showed that soft kernels had more DY counts between one and eight than hard kernels while hard kernels had more DY counts greater than eight than did soft kernels. In Roll-2, a DY count of eight translates to about 275 N per mm at the 30 mm/s deformation rate.

Since soft wheats mill into a larger number of smaller particles than hard wheats, the number of the positive slopes across the digitized interval in a force profile may be proportional to the number of particles, and the slope value may be proportional to the size of particles created by crushing. This suggestion permitted the development of a hardness measurement based on the positive slope values from the digitized force-time profile. From the initial study, 13 machine data summary parameters were selected as a data base for kernels processed by the Roll-2 system. After calibration for moisture and size, the machine data summary parameters were reduced to the six shown in Table 1.

Moisture

Conductivity was related to moisture, contact area, and force on the kernel as it was deformed and crushed between the rotor and crescent. Contact area and force change continuously during the kernel deformation process. As a result, the conductivity signal also changes even though the kernel may have uniform moisture content. Differences in kernel size, shape, orientation, and hardness also influence the force on the crescent. However, the ratio of conductivity to load cell force was nearly constant when crushing equilibrated kernels.

From kernel to kernel, the most consistent moisture measurements (Fig. 7) were near the end of the conductance profile and corresponded to the region near the maximum force value. All moisture determinations from Roll-2 were calculated from the logarithm (conductivity/force) signal at or near the maximum force value.

The results of the March 1988 moisture calibration (Fig. 8) showed that one calibration was satisfactory for hard red winter, hard red spring, and soft red winter wheat classes. This calibration was also adequate to cover the moisture range found in the 1988 National Wheat Hardness Study (Wishna, 1989) which also included classes of WW and club wheat but not durum.

Size

The contact time (Fig. 5) for smaller kernels was less than the contact time for larger kernels (Fig. 6). The initial kernel contact may occur at rotor tooth tip, or at the base of a rotor tooth (land) which represents a dimensional difference of 0.38 mm. As deformation progresses, the kernel may slip off the tooth into the land or split into two pieces with each piece separated by a tooth. When splitting or slipping occur, the force exerted by the kernel on the crescent is momentarily reduced which frequently produced negative DY values. Splitting and slipping introduce a random machine reaction to the size measurement using rotor-crescent contact time. Hard kernels were observed to require a slightly longer time to pass through the instrument than soft kernels of the same size. This may be the result of two effects: 1)that more slip occurs during hard than soft kernel crushing and 2)more rotational slowing of the rotor related to greater torque requirement for crushing hard kernels than soft kernels.

Roll-2 size measurements (Fig. 9) for the sieved size groups were highly correlated with average kernel weight ($r^2 = .916$, $N = 754$). However, the hardness interaction on the size measurement was apparent in that most of the points below the regression line were hard wheats while most points above the line were soft wheats.

Hardness

Roll-2 hardness measurements were based on the summary parameter sum 1/DY>0 and a combination of the summary parameters #DY>0 and #DY>8. The sample averages of the two hardness functions were highly correlated ($r^2 = 0.97$, $N = 253$) across samples of the five major wheat classes. The high correlation suggests that the two hardness algorithms measure similar kernel properties.

Hardness values based on the sum 1/DY>0 parameter were corrected to a reference 12 % moisture content and Roll-2 kernel size value of 35 as follows;

$$H1 = b1 + a1 \times [\text{sum } 1/DY>0 + (12-MC) \times mc1 + (35-SZ) \times sz1].$$

Hardness values based on #DY>0 and #DY>8 were corrected for moisture and size as follows;

$$H2 = b2 + a2 \times [100 \times \#DY>8/(\#DY>0 \times SZ^{0.5}) + (12-MC) \times mc2 + (35-SZ) \times sz2].$$

Where;

a = 50/(ave. HRW & HRS values - ave. SRW & WW values),
b = 75 - (ave. HRW & HRS values) x a,
MC = Roll-2 moisture content, %,
SZ = Roll-2 kernel size,
mc1 = 2.69 for sum 1/DY>0,
mc2 = 6.75 for #DY>8 function,
sz1 = 0.30 for sum 1/DY>0,
sz2 = 0.05 for #DY>8 function.

Using the scaling and moisture constants determined from the March calibration, single kernel hardness values were calculated for each sample in the NWHS reference set when the average moisture content of set was 11.6, 12.3, and 13.3 percent in March, May, and July respectively. A summary shows that (Table 2) Roll-2 average hardness values of the HRS wheats were larger than the HRW wheats, the WW wheats were between the HRW and SRW wheats, and the SRW wheats were lower than the WW wheats. This same order of hardness values for four major wheat classes also was observed among the 1200, 1987 National Wheat Hardness Study samples evaluated by FGIS (Wishna, 1989). The classing index increased from about 0.95 for a single hardness function to about 1.27 by the method including two hardness functions to reduce kernel to kernel variation.

Further studies are needed to reduce machine variability and to improve the potential for wheat classification based on the rotor-crescent crushing system. Six prototypes of the experimental system described were fabricated to investigate machine production variability and other machine performance characteristics.

SUMMARY

A single kernel crushing device was developed to determine crushing, moisture, and size characteristics at a rate of approximately 180 kernels per minute. A procedure for determining hardness of single kernels was developed with corrections for the effects of kernel moisture and size. Single kernel moisture measurement comparisons with bulk oven moisture measurements were satisfactory. Average kernel size measurements were highly correlated with average kernel weight, although a random machine interaction with single kernel size measurement was noted. Six prototypes of the experimental rotor-crescent system were assembled for further evaluation. Tests to determine the system's potential for wheat classification and inclusion in the official grain inspection process are under way.

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List of Figures

Table 1. Machine data summary parameters.

No.	Definition	Projected Relationship
1	moisture signal, A/D count	A parameter related to moisture; logarithm of the conductance to force ratio.
2	peak force, A/D count	Used to select the data points for determining moisture measurement.
3	number of DY>0	A parameter related to size based on the time a kernel exerts force on the crescent.
4	sum of 1/DY, for all DY>0, A/D count	A parameter that is proportional to hardness. Soft wheat kernels produce a large value, hard kernels produce a small value.
5	number of DY>8	A parameter that is proportional to hardness.
6	sum of DY for all DY>0, A/D count	A parameter that is related to the work required to crush a kernel.

Table 2. Summary of Roll-2 Hardness Values and Classing Efficiency for the National Wheat Hardness Reference Sample Set for Instrument Calibration Using the March 1988 calibration constants.

Sample Set Moisture,% av.	300 Kernel av. Hardness Value Durum	HRS	HRW	WW	SRW	av.*	Classing Efficiency Index*
11.6	101.2	76.3	73.7	36.4	8.0	58.3	1.27
12.3	105.7	82.1	76.1	39.0	10.3	61.9	1.27
13.3	107.0	80.9	74.9	36.8	7.7	60.3	1.29

* Excluding durum.

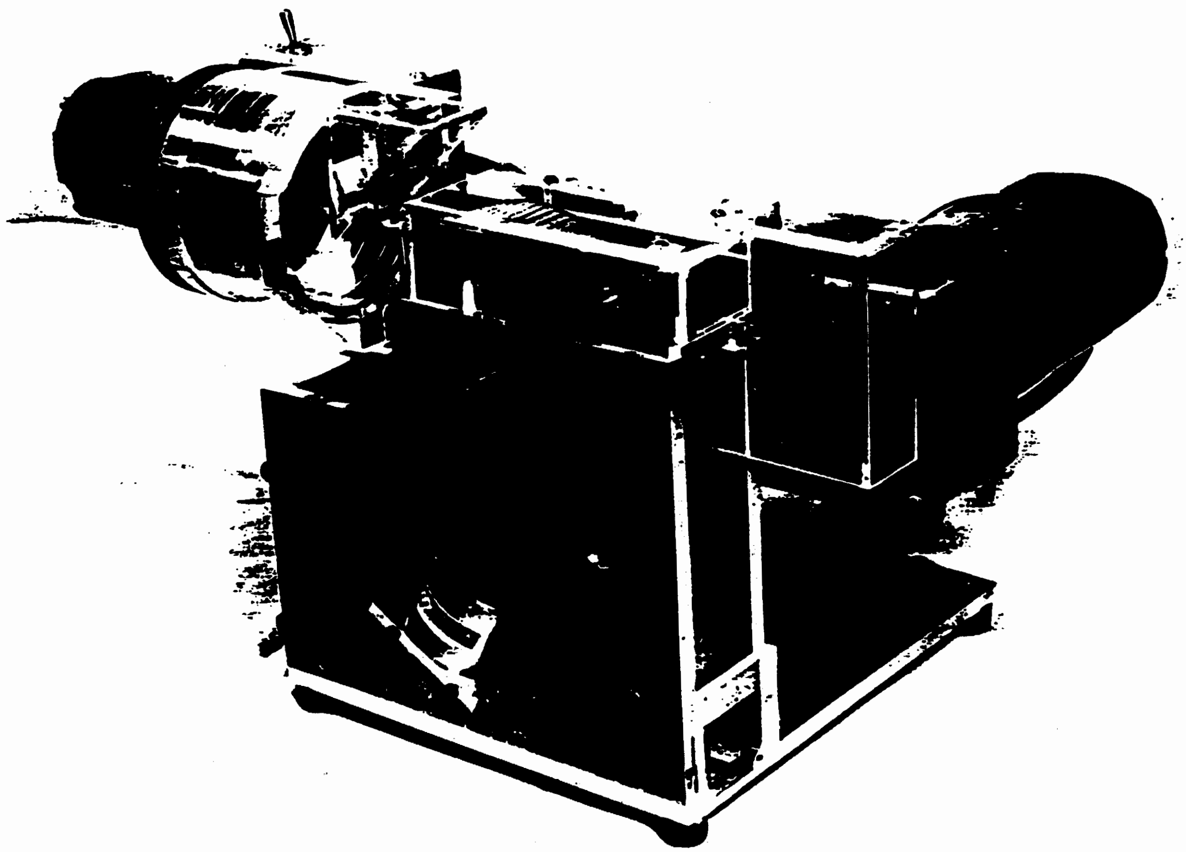

Fig. 1-Rapid single kernel crushing device with single kernel feeder.

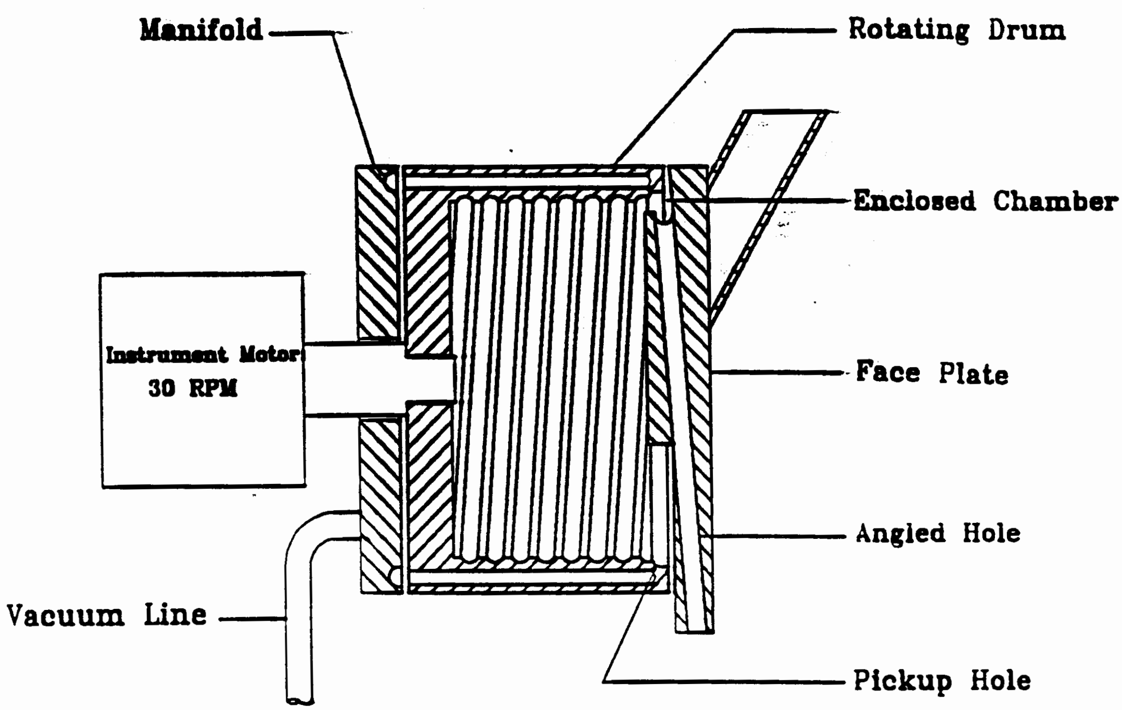

Fig. 2- Schematic of the single kernel feeder

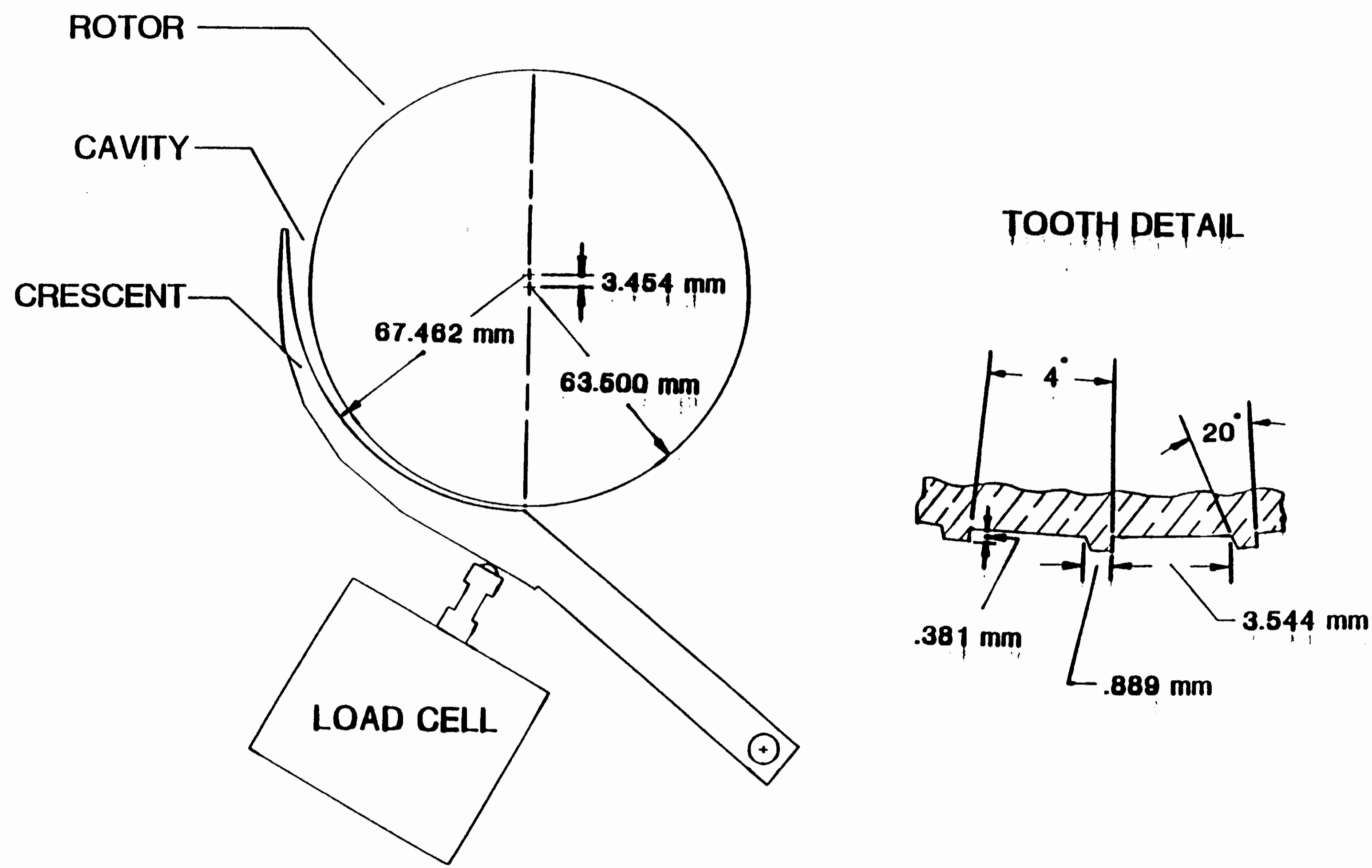

Fig. 3- Schematic of the crushing device.

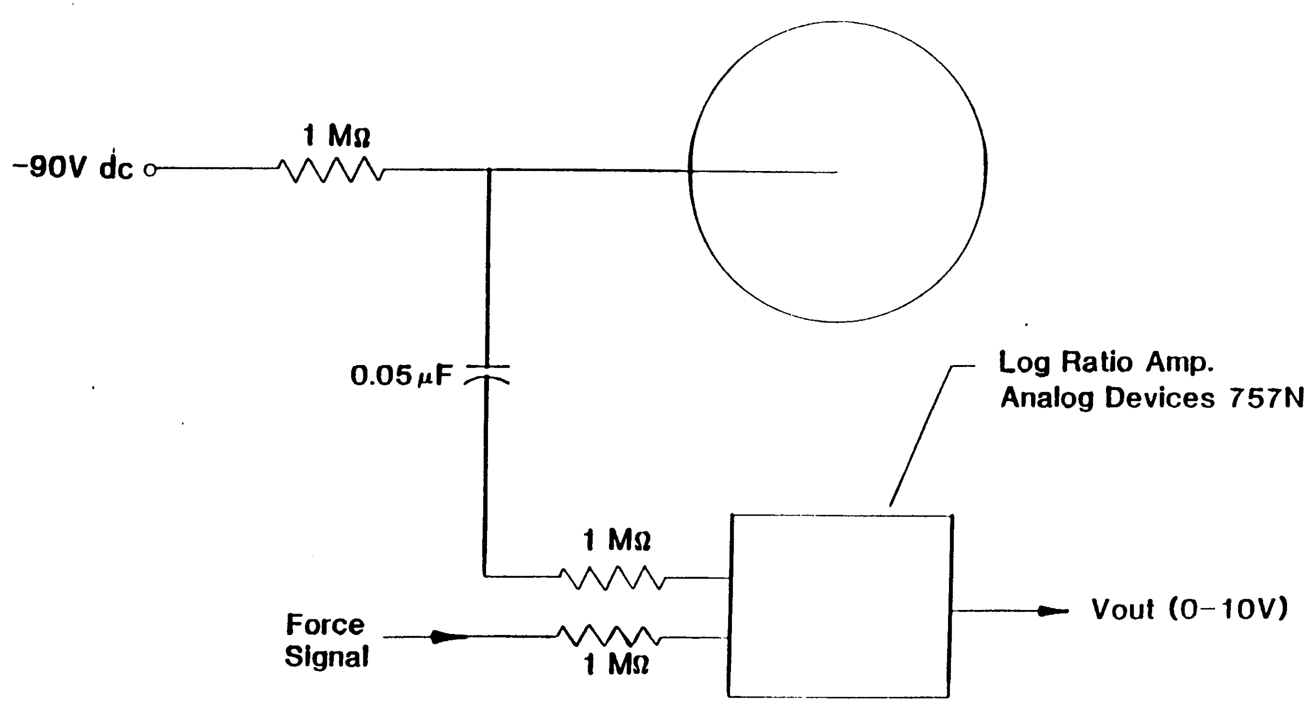

Fig. 4- Schematic of the conductivity circuit.

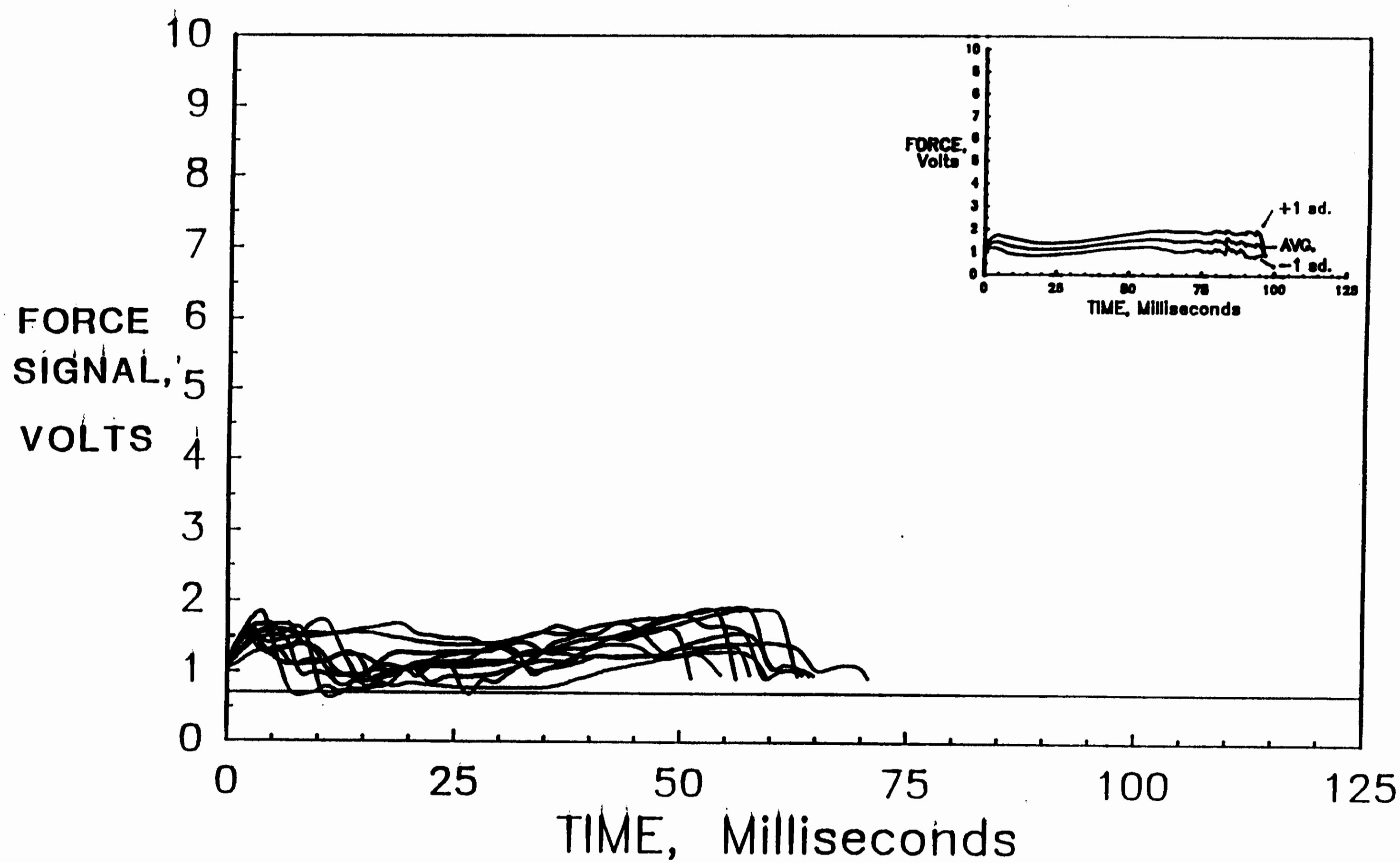

Fig. 5- Force profiles of soft red winter wheat from Roll-2. Inset shows the average profile and the profile +/- 1 s.d. for 320 kernels.

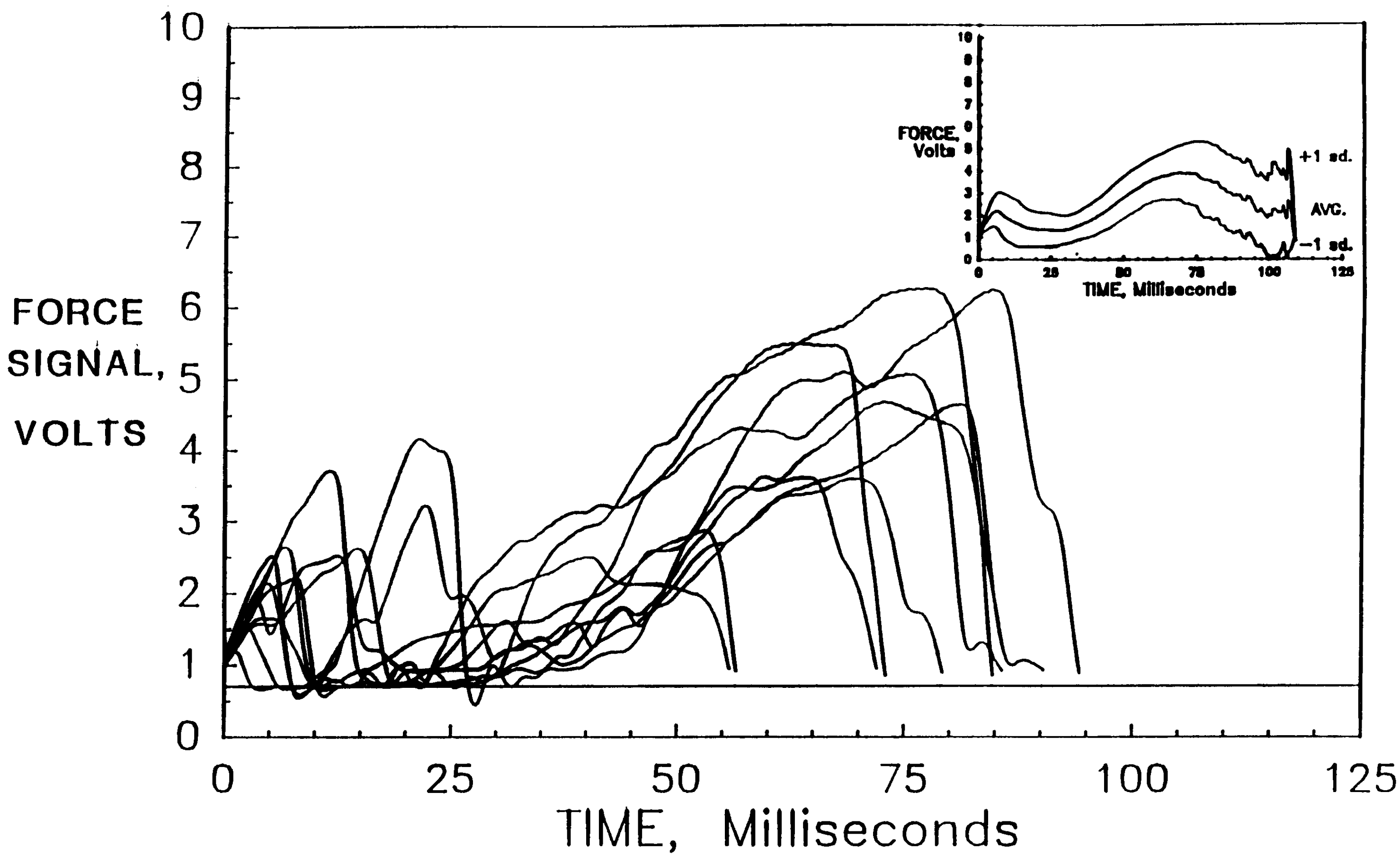

Fig. 6- Force profiles of hard red spring wheat from Roll-2. Inset shows the average profile and the profile +/- 1 s.d. for 320 kernels.

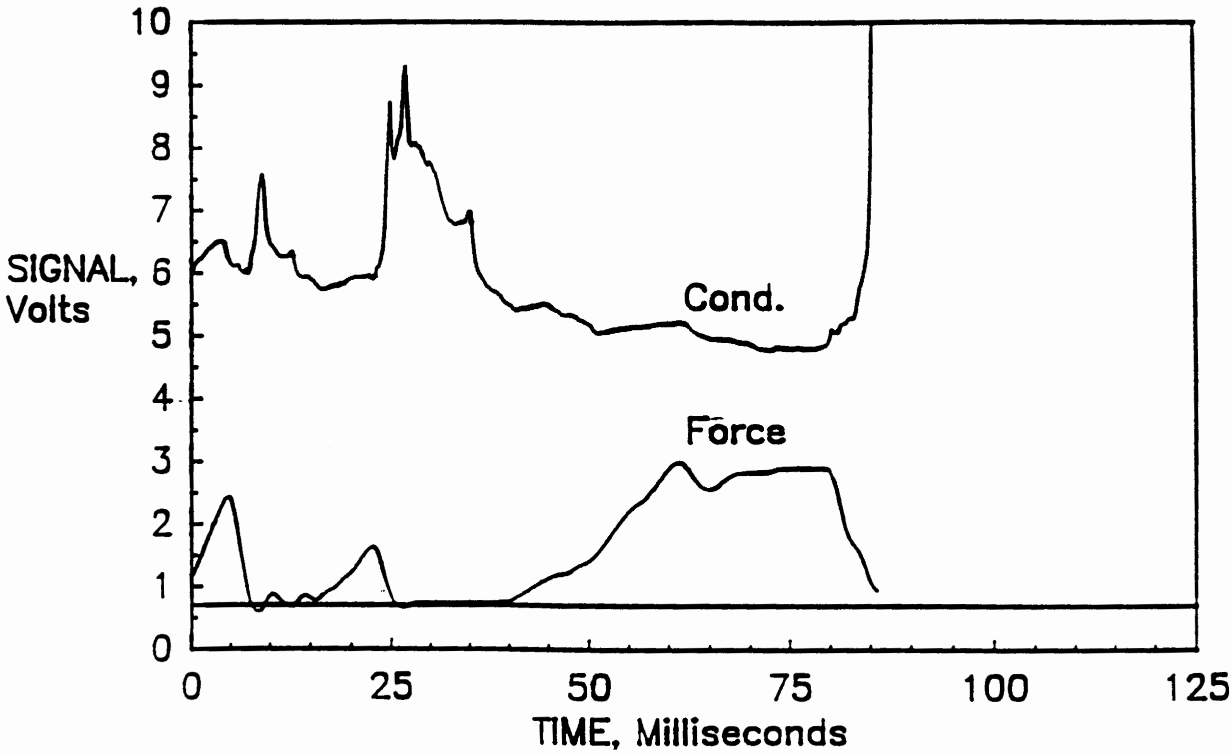

Fig. 7 - Force and conductance profile of a wheat kernel from Roll-2. Conductance signal is the logarithm of conductance/force ratio.

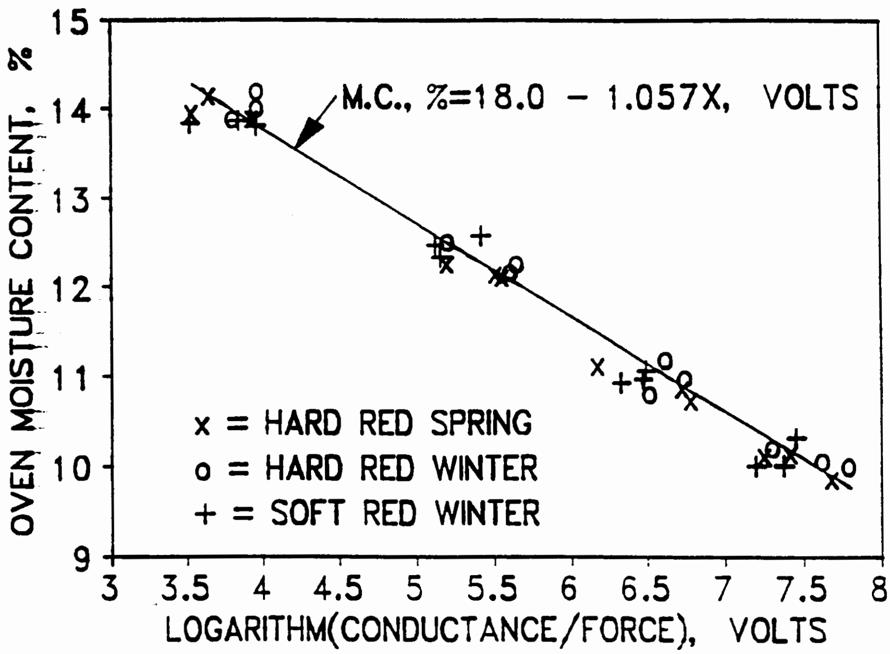

FIG. 8- March 1988 moisture calibration for Roll-2.

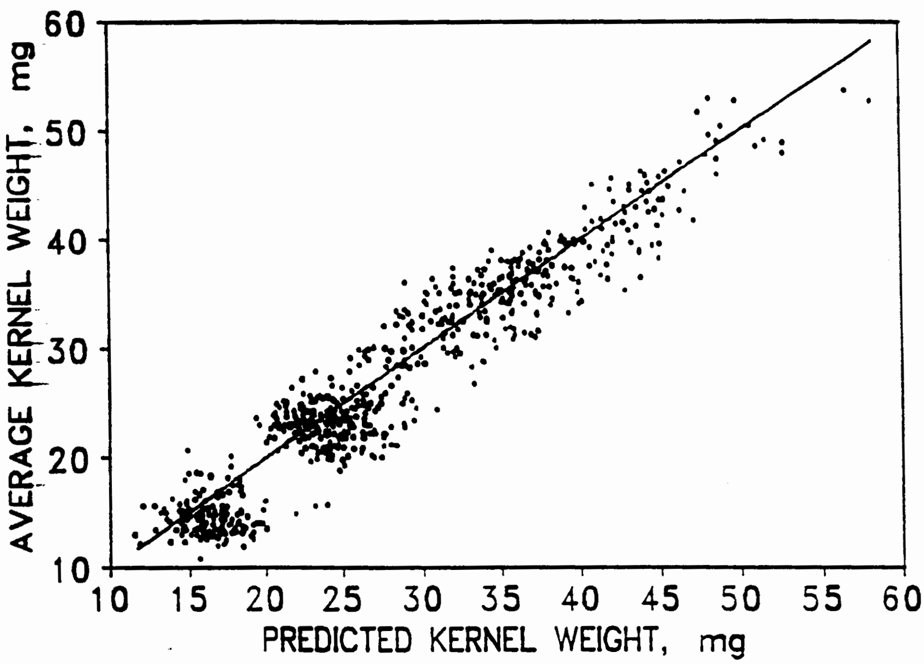

Fig. 9- Results of the size calibration for Roll-2 showing predicted kernel weight vs. kernel weight.