AN ELECTRONIC RECORDING DOUGH MIXER

I. The Apparatus[1]

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ABSTRACT

A recording mixer for 5- or 10-g. flour samples is described. It has a sensitive electronic torque-recording system. The sample bowl is fixed rigidly, and damping of its suspension is not required. The path traced by the mixing pins is constant in relation to the pins in the bowl. Calibration of the apparatus is checked by gravity weights and is changed by simple adjustments. High-frequency torque fluctuations can be recorded to show individual shearing operations on the dough during mixing. Maximum shear strength of the dough during mixing can be estimated from the records. Several configurations of the apparatus and typical dough-development curves obtained are shown. The accuracy and performance of the machine are discussed.

The recording mixer is an important apparatus in any wheat quality laboratory. Laboratories engaged in genetic programs are supplied with limited quantities of wheat for study. The apparatus described here is designed to test small samples (5 to 10 g.) in such a program.

The method developed by Swanson and Working (1,2) and Swanson and Kroeker (3), and noted by Heald (4), is a standard physical dough test (AACC Method 54-40). The method is based on a mixer in which the torque reaction of the mixing bowl is recorded. The torque transmitted from the mixing head to the bowl by the dough is proportional to the physical properties of the dough, that is, its shear strength and elasticity. This torque is used as an index of dough strength. Swanson described two torque-recording systems which are, first, a wattmeter measuring power absorbed by the motor, and second, the twist of a rod (2). Anderson (5) also described a wattmeter for testing batters. In a commercial unit (mixograph), the bowl is mounted on a pivoted arm restrained by a spring. A pen on the arm records its movement and thus records the torsion applied to the bowl. A mechanical damper limits oscillations of the arm. The mixograph is widely used, but it is designed for 25- to 35-g. samples.

A measuring instrument should be calibrated by independent means for standardization. With recording mixers, a curve relating

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torque to chart reading is required and this relationship should be linear. Standardization with only a standard flour is not suitable, since flour is not inert and changes with time. There are several disadvantages associated with previously published designs which make interlaboratory standardization difficult (6). Friction in a mechanical recording system is not constant and cannot be controlled. In the measurement of torque by the power absorbed by the mixing motor (2,5), with the use of a wattmeter, friction variations in the motor and mixing-head bearings cause errors. The electrical efficiency of the motor is another variable which must be considered.

Where the measurement of a force requires displacement within the recording system, as in the mixograph, friction limits the resolution of measurement and accuracy of an independent calibration method. For example, two mixographs checked by the authors required a torque of 8% of full scale (f.s.) to overcome friction with the spring disconnected. To initiate movement of the recording arm at zero with the spring connected required 12% of f.s. torque. The mass and pre-tension of the spring introduces an additional error of 4%. The friction must be overcome in both directions, and therefore the calibration must be checked in both directions. If changes are observed, cleaning the moving parts, installing a new spring or adjusting its pre-tension might rectify the error. Minor adjustments of span or sensitivity are not available; it is only possible to change ranges, i.e., spring position. The torque indicated at each graduation on the chart cannot be measured unless the recording arm is moved to overcome breakout friction (the minimum torque required to initiate movement, which is greater than the torque required to sustain motion). Calibration is thus a tedious procedure with a hand-held spring scale. Gravity weights can be used, but the recording mechanism is then stationary and breakout friction is not recorded.

In the mixograph the bowl rotates with the measuring arm. As a result, the mixing pins can strike the fixed pins at either the f.s. or the zero position if the pins are misaligned. During mixing, clearances between the pins in the bowl and the mixing head are constantly changing. As the bowl rotates under applied torque the clearance between the pins is changed, and this alters the mixing effect on the dough; thus the mixing process affects the measurement, and the method of measurement affects the mixing process. The frequency of torsion fluctuations during the mixing process is 4 cycles per second (c.p.s.). This frequency is beyond the capabilities of a damped mechanical recording system.

A recording mixer for small samples, described by Malloch (7), also uses a mechanical recording system and therefore has the same disadvantages. In addition, the mixing pins are of different design, and direct comparison of its results with mixograph data is difficult. However, the methods described below can be applied to Malloch's design and any other type of recording mixer.

The new design eliminates these problems, or at least reduces them to negligible proportions, because friction is almost eliminated from the torque-measuring system. The new mixer offers the following advantages: ease of calibration, greater accuracy, a wide range of sensitivities, rectilinear records, and elimination of sample bowl movement. The study of high-frequency torsion fluctuations is possible, which may be of considerable interest in a study of the rheological properties of dough.

Description of Apparatus

The design of the bowl and mixing head is similar to that of the Swanson and Working apparatus (1), except that they are reduced in size to accommodate a 5- to 10-g. sample of flour.

The mechanism for measuring resistance of the dough during mixing is different from those of existing designs. The mixing bowl *B* (Fig. 1) is clamped to a platform *N* suspended on a spindle *H* mounted in precision cone-type bearings *I*. A stainless-steel beam *K* is bolted to

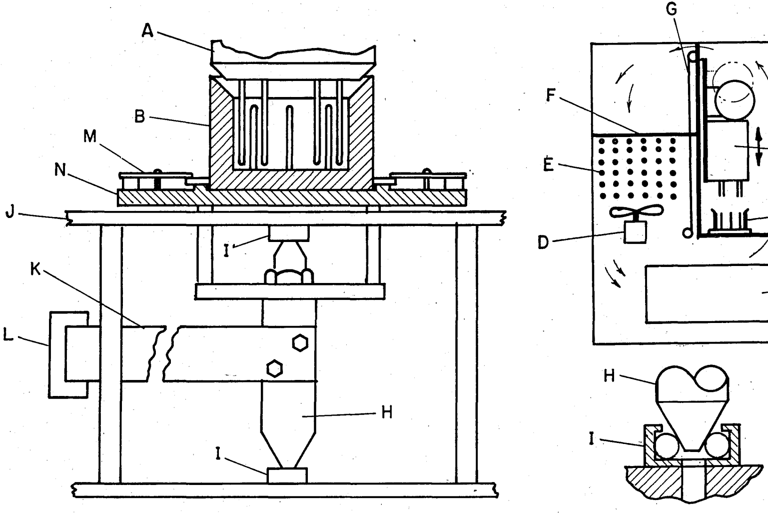

Fig. 1. Diagram of apparatus: A, mixing head and drive motor; B, mixing bowl; C, electronic equipment; D, fan; E, cooling coil; F, filter; G, counterbalance spring; H, spindle; I, cone bearing; J, main frame; K, steel beam; L, clamp; M, mixing bowl clamp; N, bowl support platform.

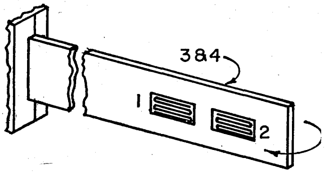

Fig. 2. Torque transducer showing strain gages. 1 to 4: the gages are placed close to the spindle where the strain in the beam is maximum.

the spindle *H* and clamped at the other end *L* to the main frame *J*, to resist rotation of the platform and bowl. The torque sensor is thus a beam clamped at one end and subjected to torsion at the other (Fig. 2); this produces bending strains in the beam. Four strain gages are bonded to the beam, two at each side, to detect the strains in the strip. The four gages are connected in a Wheatstone bridge (*B*, Fig. 3). Space does not allow a full description of strain gages; an excellent introduction is available (8). The natural frequency of the bowl, suspension, and strain-gaged beam assembly is 50 c.p.s. Therefore, the mechanism is suitable for detecting torsional fluctuations applied to the bowl at frequencies up to about 30 c.p.s.

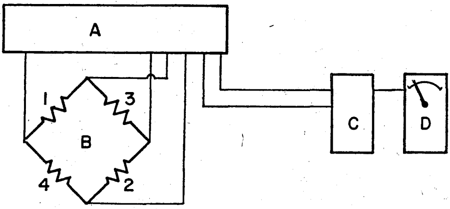

Fig. 3. Circuit diagram: A, strain gage module (Model S.R.B. 200EP, Endevco, Pasadena, Calif.); B, strain gages connected in bridge circuit; C, amplifier (Model 114, Rustrak Inst. Co., Manchester, N.H.); D, recorder 100 microamp. (Rustrak Inst. Co.).

A strain gage module (*A*, Fig. 3) supplies voltage to the bridge and has controls to adjust the voltage and balance the bridge output under zero torque conditions. The output is amplified *C* and recorded *D*. The pointer of the recorder is pressed 30 times per min. against pressure-sensitive paper. Thus, the records are random points in the development curve through which a mean value can be drawn. Calibration is made with a gravity weight on a cord wrapped around a pulley inserted in the bowl holder, thus applying a known torque to the torsion sensor (Fig. 4, D). To calibrate the apparatus, the bridge is first balanced at zero torque so that the recorder reads zero. The maximum torque is then applied and the gain of the amplifier ad-

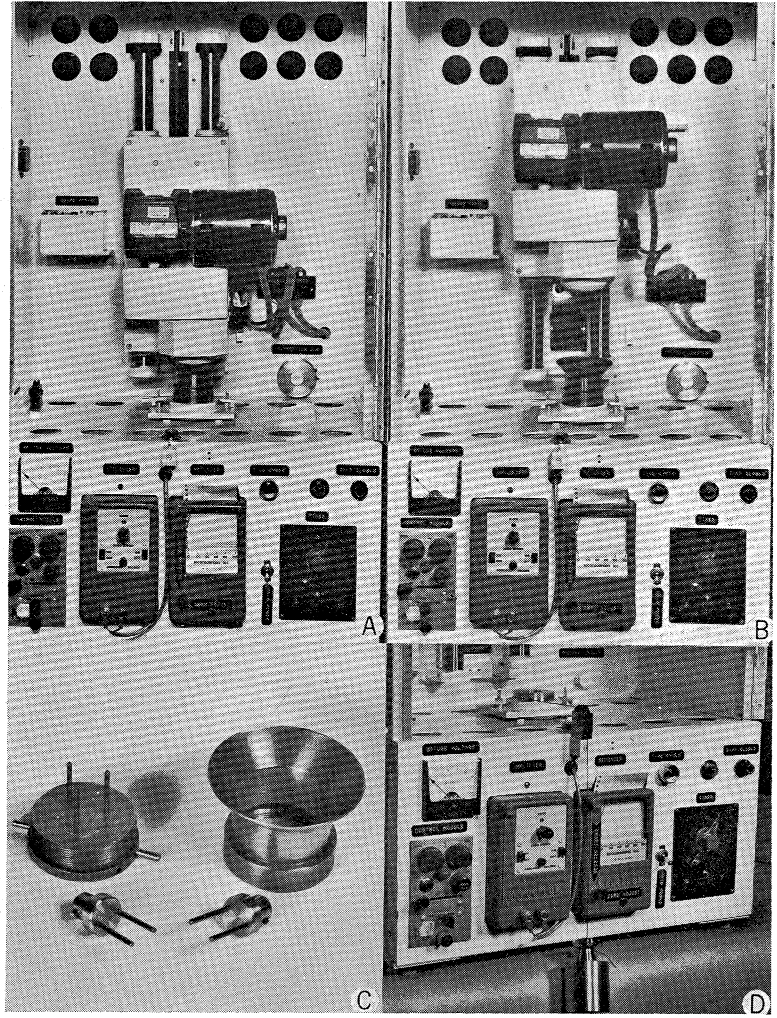

Fig. 4. The apparatus: A, mixing head in operation; B, mixing head raised; C, mixing bowl and mixing head pins disassembled; D, calibration. The weight applies torque to the mixing bowl suspension.

justed so that the recorder reads full scale. A calibration curve of torque *vs.* chart reading is then plotted by applying torques in discrete increments up to the maximum.

The motor and mixing head move up and down vertically, their weight being counterbalanced by a constant-force spring (*G*, Fig. 1). The mixer will not operate until the head is fully lowered into the mixing position, when a microswitch is closed; it then runs at 96 r.p.m.

for periods selected at a timer. The apparatus is housed in a cabinet 18 by 20 by 32 in. high with a clear plastic door at the front (Fig. 4, A). Constant temperature (25°C.) is achieved in the cabinet by a fan *D* circulating air filtered at *F*, through a cooling coil *E* (Fig. 1). When the temperature rises above the setting of a thermostat, cooling water is admitted to the coil by a solenoid valve. The mixing bowl can be disassembled and the pins of the mixing head removed for cleaning (Fig. 4, C).

TABLE I

TYPICAL ELECTRONIC RECORDING SYSTEMS USED WITH THE NEW MIXER

CONFIGURATION	RECORDER			AMPLIFIER	TYPICAL SENSITIVITY OF MIXER	
	Type	Frequency Response	Chart Width		5-g. Sample	10-g. Sample
			in.		*cmg.*	*cmg.*
1	T-Y[a]	0.6 sec. f.s.	10.0	Daytronic[b]	1,000	1,500
2	CEC[c]	600.0 c.p.s.	6.0	Ellis[d]	3,000	3,750
3	Microammeter[e]	6.6 sec. f.s.[f]	4.5	Ellis[d]	750	1,500
4	Rustrak[g]	1.0 sec. f.s.	2.0	See text	750	1,500

[a] Model HR-97T-2; Houston Instrument Corp., Houston, Texas.
[b] Model 300CF with Type 80 plug-in; Daytronic Corp., Dayton, Ohio.
[c] Model 5-124 with Type 7-323 galvanometer; Consolidated Electrodynamics Corp., Pasadena, Calif.
[d] Model B.A.M. 1 with A2 driver amplifier; Ellis Associates, Pelham, N.Y.
[e] Model A601C, Easterline Angus Instrument Corp., Indianapolis, Indiana.
[f] Depends on type of amplifier used and can range upward from 1.0 sec.
[g] See text.

The instrumentation used in the recording mixer can be replaced by other types of electronic equipment and recorders (Table I), to record curves on various scales and emphasize different features. Curves can be recorded on rectilinear-grid paper up to 12 in. wide by using a potentiometer or T-Y recorder. Recorders with high frequency response can be used to record each shearing operation on the dough. The choice depends on the equipment at hand and the application of the mixer. For example, curves whose appearance is similar to those produced by the mixograph can be made by using a recording microammeter with circular-arc recording paper.

Results

The rotation of the sample bowl was less than 0.3° under the maximum torque required to mix strong doughs. The range of sensitivities was from 400 cmg. up to any desired range. Calibration curves of torque *vs.* chart reading were almost linear. The maximum nonlinearity occurred at the maximum sensitivity and was ± 0.6% of f.s. Hysteresis was not detected in the calibration curves of increasing and decreasing torque and was therefore assumed to be less than 0.1% of f.s. The repeatability and accuracy of the system were within ± 0.5%. There was a slight drift of zero position of the recording system with time. This was corrected before each sample was started, by a zero

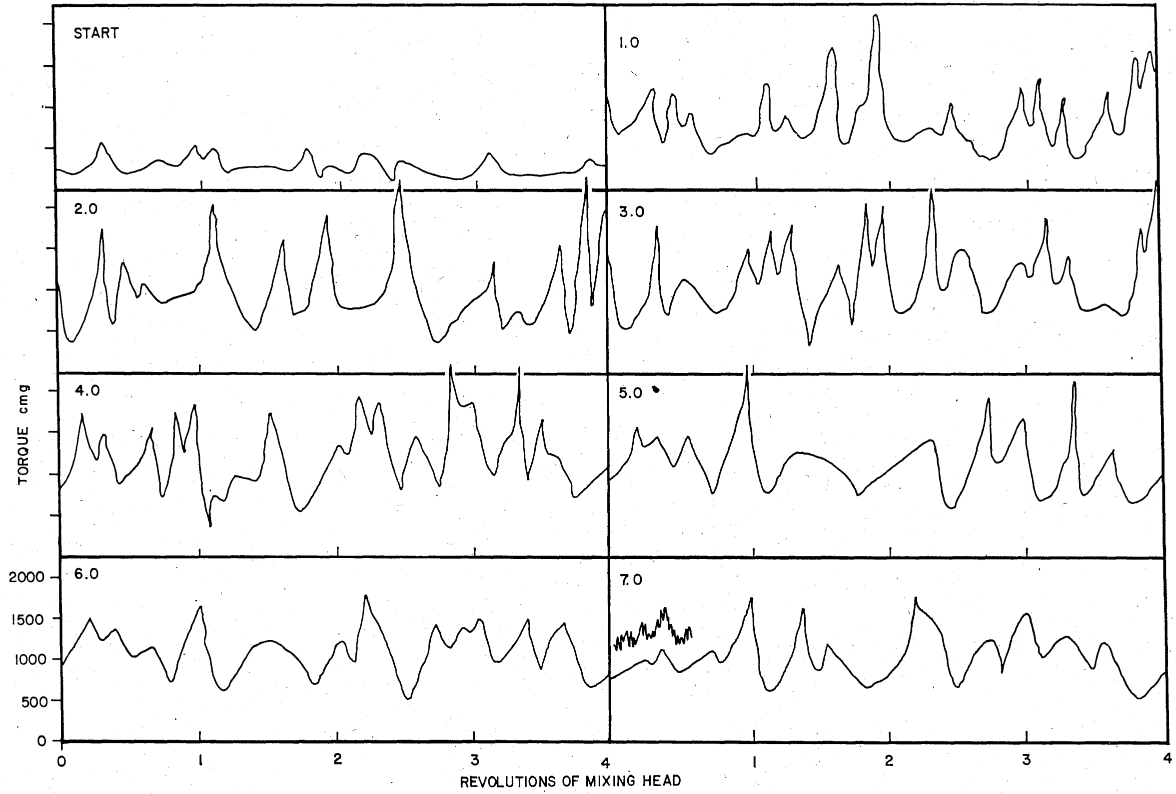

Fig. 5. Comparison of torsional variations during mixing for bread flour taken at 1.0-min. intervals, showing one complete cycle of the mixing head using a C.E.C. recorder (configuration No. 2, Table I). The illustrations are copies of the records with minor variations from the gearing, smoothed out. An inset at 7.0 min. shows an exact copy of a portion of the record.

control on the amplifier. Drift of sensitivity with time was not observed.

It was observed that the frequency response of the recording system had an effect on the result. The torsional loads during mixing fluctuated at approximately 4 c.p.s. (Fig. 5), with minor variations at a frequency of 40 c.p.s. superimposed, caused by vibrations of the gearing system driving the mixing head. The epicyclic gearing of the mixing head produced a mixing pattern which is repeated every four revolutions (Fig. 5).

Whereas a full-scale torque of 1,500 cmg. was sufficient to record maximum peaks, that is, the effect of the maximum shear stress in the dough when a T-Y recorder was used (0.6 sec. response time for f.s.), a f.s. torque of 3,750 cmg. was necessary with an oscillograph recorder (frequency response 600 c.p.s.), which could record the true peaks in the curve. If the frequency response of the recorder is too low, the true peaks and valleys in the signal cannot be followed by the recorder; they are clipped off (Fig. 6). Thus, the record shows a much narrower torque range than is actually present. The peak torque is proportional to the maximum shear stress in the dough during mixing as the mixing pins shear through the dough in the bowl. The mean torque is related to the combined effect of elasticity and shear strength of the dough. Therefore, both mean and maximum torque are of interest, since they indicate the development of dough strength.

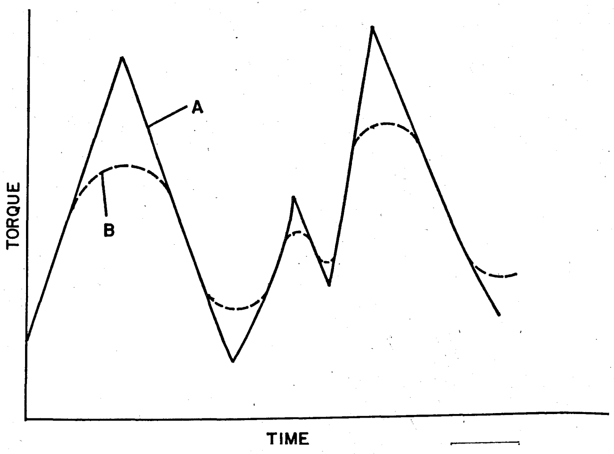

Fig. 6. Clipping effect of low-frequency-response recorder. A, actual torque; B, torque recorded if frequency response of recorder is too low.

Discussion

Any system for recording torsion is best calibrated by gravity weights. These at small loads are accurate, inexpensive, and easy to apply. Hysteresis was not detectable in the electronic calibration curves of increasing or decreasing torque; therefore, friction in the spindle bearings was negligible. After a range was selected and a calibration curve plotted to check for linearity, the calibration was

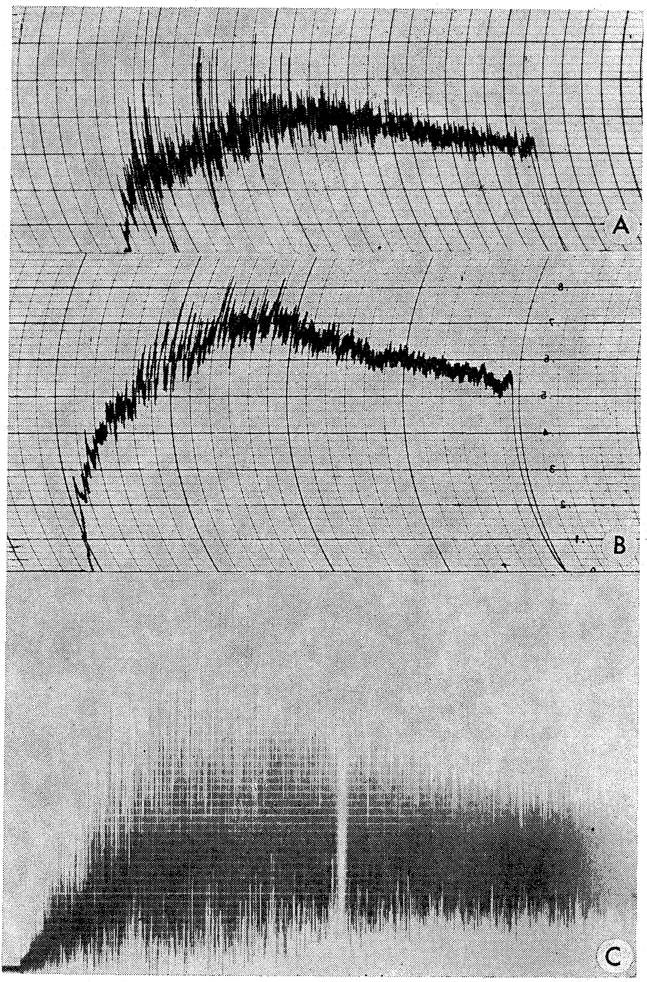

Fig. 7. Typical 7.5-min. development curves for commercial bread flour. For details of the electronic systems used, see Table I. A, 30-g. National-Mixograph with mechanical recording; B, 10-g. mixer recorded with a recording microammeter (configuration No. 3); C, 10-g. mixer recorded with a C.E.C. 600 c.p.s. recorder (configuration No. 2).

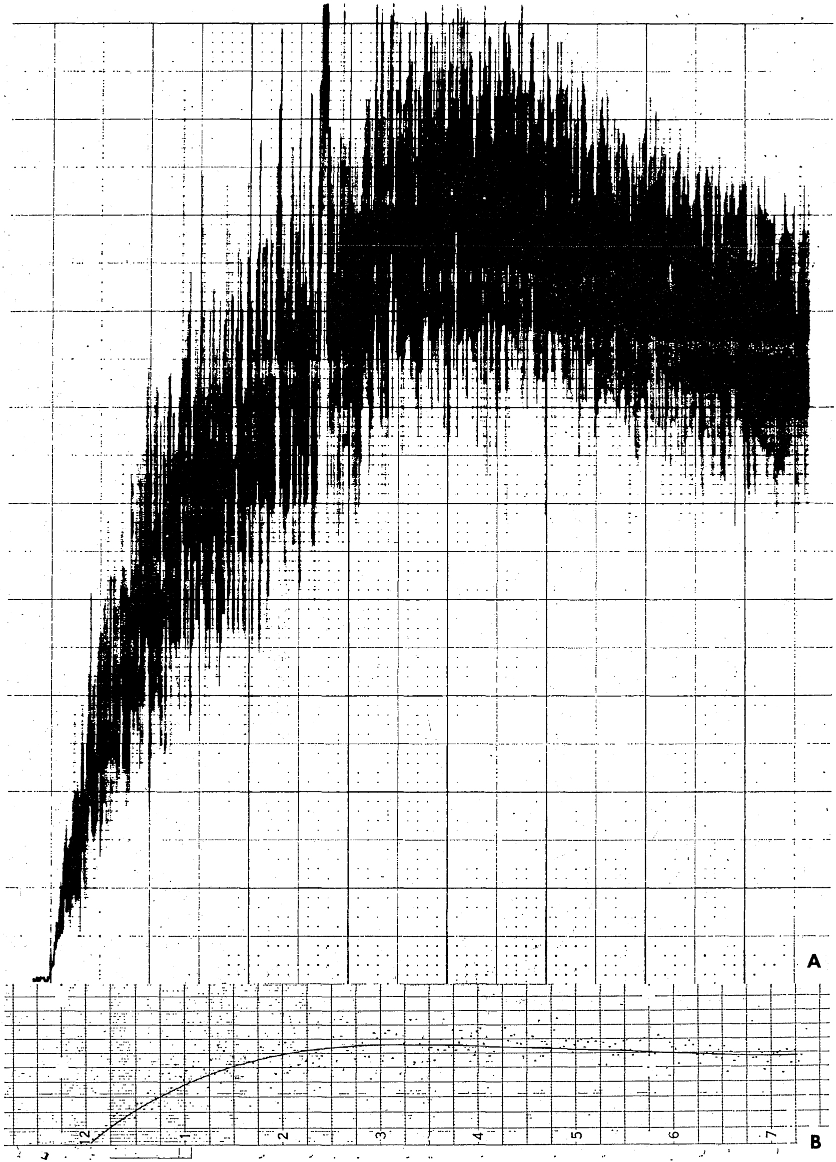

Fig. 8. Continuation of Fig. 7. A, 10-g. mixer recorded with a T-Y potentiometric recorder (configuration No. 1); B, 10-g. mixer recorded with a Rustrak recorder (configuration No. 4).

rapidly verified by testing the zero and f.s. reading only. This is not possible with the mixograph because of the large curvature of its calibration line, which must be checked at several intermediate points.

The advantage of plotting development curves on large-scale charts is shown in Fig. 8, A. Measurements taken from these curves are more accurate than those obtained with narrower charts because of the higher resolution. If a high-frequency recorder is used with the chart paper running at high speed, the individual pack-squeeze-pull-tear (1) operations on the dough can be recorded to show the maximum and minimum values of the torque during mixing (Fig. 5). Thus, an index of maximum shear stress in the dough is available. For example, with the chart running at slow speed the maximum shear stress in the dough during mixing can be estimated from the area under a curve drawn over the peak torque values of a record such as that shown in Fig. 7, C. This offers the possibility of new methods of interpreting curves, by measuring the individual torque peaks and comparing patterns at different stages in the mixing process, or using the maximum shear stress as a measure of dough development.

The precise value of individual torque variations is possibly not a major consideration in interpreting development curves for many purposes, but the width of the development curve at each stage of the mixing process is, since it indicates the variation of shear stress in the dough during mixing. If the peaks are not recorded as in a mechanical system, the mean of the curve, commonly used as an index, is incorrect, because the upper and lower limits of the fluctuations are not recorded accurately. This effect is not the same for all doughs, since the higher the peaks the greater is the clipping effect of a low-frequency-response recorder. Therefore, the recording system should record the torque fluctuations accurately; these can then be averaged by interpretation. If the wide curve produced is considered undesirable, it can be reduced by several electronic methods and the other advantages of electronic recording will be retained. For example, electronic recorders with a very low frequency response, which plot the mean of a varying signal accurately, are available.

Conclusions

The recording mixer described is versatile and is an improvement over existing designs. The cost of an electronic torque-recording system is justified, since it can produce more accurate records on a wide range of recording charts. The accuracy of calibration by gravity weights facilitates interlaboratory standardization. The wide range of sensitivities can be used to record curves for weak and strong flours on the same scale. Samples of 5 or 10 g. can be used in place of the present 30-g. sample, and, if the problem of mixer design can be overcome, smaller samples, such as 2-g., may be possible. These features are of great value to the cereal chemist studying dough quality.

While more work is required to interpret the electronically recorded curves showing actual torque variations, the additional accurate data increase the value of the mixograph method as a research instrument. The ability to estimate maximum shear stress during mixing increases the information on which an evaluation of flour quality can be based. However, considerable work is required to establish the relation between torsion on the bowl and rheological properties of the dough.

Acknowledgment

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