Mixogram Analysis Based on Mixograph Dynamics

D. L. Brabec,[1] M. D. Shogren,[1] and R. Rousser[1]

ABSTRACT

Mixogram data is produced from a combination of dough and machine responses. The machine response of a mixograph is related to the machine's cyclic mixing motion and the spring-mass characteristic of the machine and dough. Mixographs have many configurations, such as moving- and fixed-platform systems. To make the results from different mixograph configurations comparable, the dough response needs to be extracted from the data, and the data needs to be normalized to a standard reference value. This study identified several machine characteristics and their effects on the mixogram data. A standard 10-g mixograph was fitted with sensors that measured the position of the swinging platform. A second 10-g mixograph was fitted to measure the torque for a 10-g fixed-platform system. Both instruments were equipped with encoders to monitor mixing position and signal the completion of each mixing cycle. Synchronization of data collection with the mixing cycles removed harmonic variations due to the nature of the mixing and allowed for accurate descriptions of the mixing torque. The average mixing torque appeared identical for both the moving- and fixed-bowl systems. There was a large difference in the standard deviation of the systems. The standard deviation was normalized to match based on the spring-mass response versus the mixing rate.

The mixograph has been described and its development history detailed by Shogren (8). Additional descriptions and operating procedures for a 10-g mixograph, are discussed in Finney and Shogren (3) and AACC Approved Method 54-40A (1).

Several researchers have created an interface between the mixograph and data collectors to digitally collect and automatically analyze mixogram data. Modifications can be made to convert a 10-g moving-bowl mixograph to one in which the bowl and its platform rotate only enough to activate a load cell—referred to as a fixed-bowl system. Many researchers have contributed to the development of systems that can electronically acquire dough-mixing data, including Voisey and coworkers (10), Rubenthaler and King (7), Navickis and coworkers (6), Walker and Walker (11), Wooding and Walker (12), and Gras and coworkers (4).

A mixograph has two mixing-pin pairs or four moving pins. The moving pins start at different locations, but all trace the same epitrochoid path. Figure 1 shows the epitrochoid path with three stationary bowl pins for each 16° of input shaft rotation. For the moving pins to complete a mixing cycle, four revolutions of the input shaft are required.

Steele and coworkers (9) have developed mathematical equations to express the position, velocity, and relative torque contributions for each of the four mixing pins (Fig. 2). Their position equations demonstrate that all pins traverse the same path during the four revolutions of the input shaft (1,440°). The lower waveforms in Fig. 2 represent the simulated torque for the four moving pins. Each relative torque waveform was determined based on pin velocity and radial distance. Maximum torque was determined while the pins were positioned farthest from the center and where the pins were moving the fastest. The summation of all pins produced a simulated mixing pattern of six subcycles per mixing cycle, representing the torque put into the dough, not the response from the dough and mixing operation.

Mixogram data is produced from a combination of dough and mixograph instrument forces during mixing. Our objectives were to characterize the cyclic nature of a mixograph and its effect on mixogram patterns, as well as to measure the mixogram in terms of torque rather than chart position and to characterize the spring-mass of each system. System characteristics cause moving and fixed data to appear to be widely different. The dough response, however, should be similar in fixed- and moving-bowl systems. By synchronizing the data acquisition to each mixing cycle and by normalizing the spring-mass response, the average torque and standard deviations for fixed- and moving-bowl mixograph systems can be compared.

MATERIALS AND METHODS

Two standard moving-platform 10-g mixographs were modified for use in this study. A rotary position sensor (Schaevitz, Pennasauken, NJ) was attached to the bottom of the platform shaft of one mixograph, allowing collection of mixing data either electronically or with pen and chart paper. A second mixograph was converted into a fixed-platform instrument by attaching the shaft of the platform to a torque sensor (Transducer Technique, Temecula, CA).

Chart position is commonly used as the scale of the mixograph and can represent different values of torque depending on the

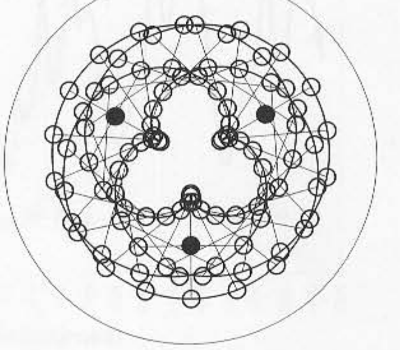

Fig. 1. Epitrochoid path of mixing pins.

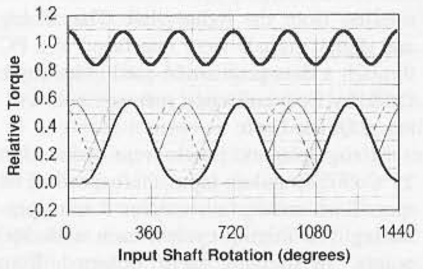

Fig. 2. Summation (upper curve) and individual pin (lower curve) mixing torque simulation.

[1] Engineering research technician, research food technologist (retired), and instrument designer, respectively, USDA-ARS, Grain Marketing and Production Research Center, 1515 College Ave., Manhattan, KS 66502.

Publication no. W-2002-0208-01R.

spring setting of the instrument. Chart position is a relative measure, while torque is an absolute measure. Different 10-g systems and flours can be compared easily when results are given in units of torque.

The mixograph systems were calibrated in units of torque. A specially designed calibration fixture and pulley were mounted to the bowl platform and mixograph chassis to facilitate the use of calibration weights. For a standard 10-g moving-platform system, torque at 50% chart paper position was about 160 mN·m. For our fixed system, the maximum possible torque was 750 mN·m.

The basic property of a spring-mass system is its response time. Instrument response time varies with platform mass and mass distribution, dampening coefficient or friction of the bearings, and spring constant (5). The time for the torque to move from maximum to zero torque was measured. For the fixed-bowl system, the platform and empty bowl were deflected to overload stop and released. The resulting oscillating torque response was recorded (Fig. 3). For the moving-bowl system, the empty bowl, platform, and spring were extended to the full-scale chart line and released. The time for the platform to move from full-scale to zero torque was recorded electronically.

For the fixed system, the effects of varied bowl positions were studied. These effects could not be quantified with the moving-bowl system because the positions of the bowl pins were allowed to vary over a 34° range of motion. However, the positions of the bowl pins were constant in the fixed system. To study the effect of the bowl pins relative to the moving pins, the bowl platform was adjustable, with positions at middle and +14° and –14° of the midposition. The midpositions of the bowl pins are as shown in Fig. 1. The test positions were similar to the 10, 50, and 90% chart line positions for a moving system. A hard wheat flour and a soft wheat flour were used for the bowl position testing.

In both systems, an encoder was mounted to the top of the mixograph (Fig. 4). The encoders were driven from the input shaft of the mixing pins with a set of gears, mechanically linking data collection to moving-pin position and mixing cycle. The encoders produced two pulsing signals. One triggered the collection of torque data after each 4° of movement. The other signaled the end of each mixing cycle or each 1,440° of rotation from the input shaft. The analog and digital signals were interfaced to a PC through a data acquisition card (Metrabyte DAS16). Data collection software was written in Quick-Basic.

Mixographs and bowls were operated at 25°C (77°F) and an input shaft speed of 88 rpm. Each mixograph ran for 8 min, producing 176 mixing cycles, each with 360 points. Mixograms were obtained from three flours with distinctly different mixing characteristics. The flours were obtained from reference stock held by the USDA

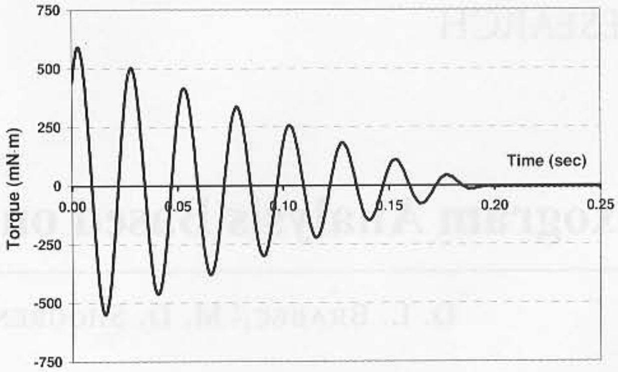

Fig. 3. Spring-mass response for 10-g fixed-bowl mixograph.

Hard Winter Wheat Quality Laboratory (Manhattan, KS). The first flour had a medium mixing development time and sustained mixing strength after the peak. The second flour had a long development time. The third flour had low mixing tolerance, as indicated by the rapid decrease after peak.

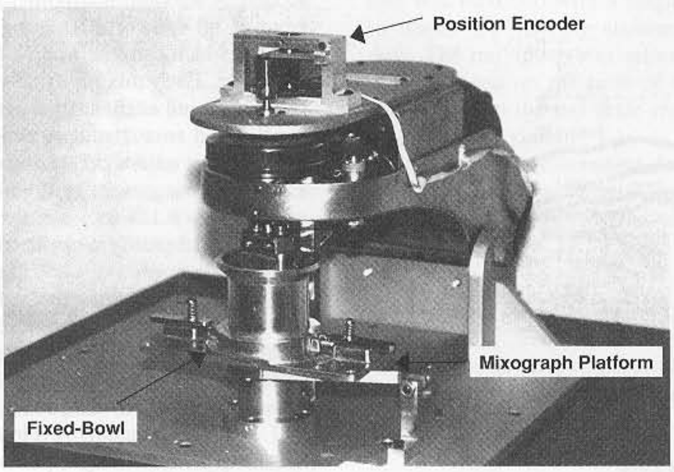

Fig. 4. Modified 10-g fixed-bowl mixograph with position encoder.

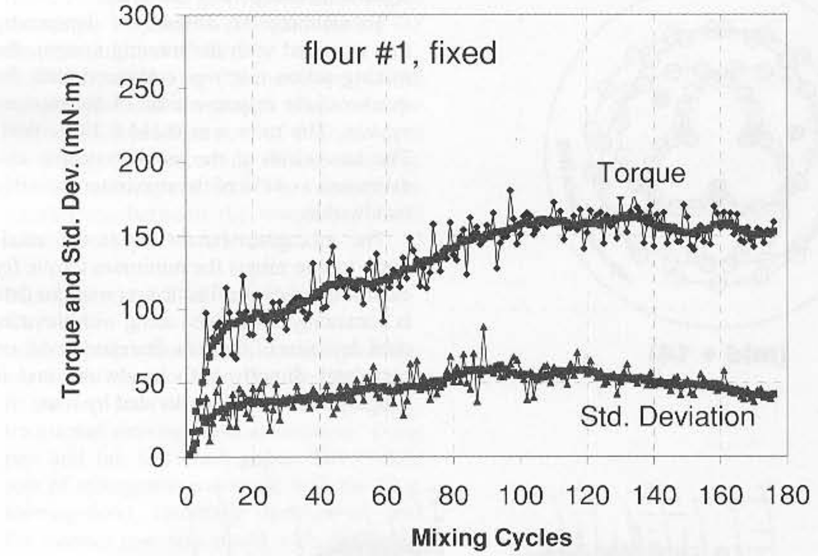

Fig. 5. Electronic mixogram of hard wheat flour.

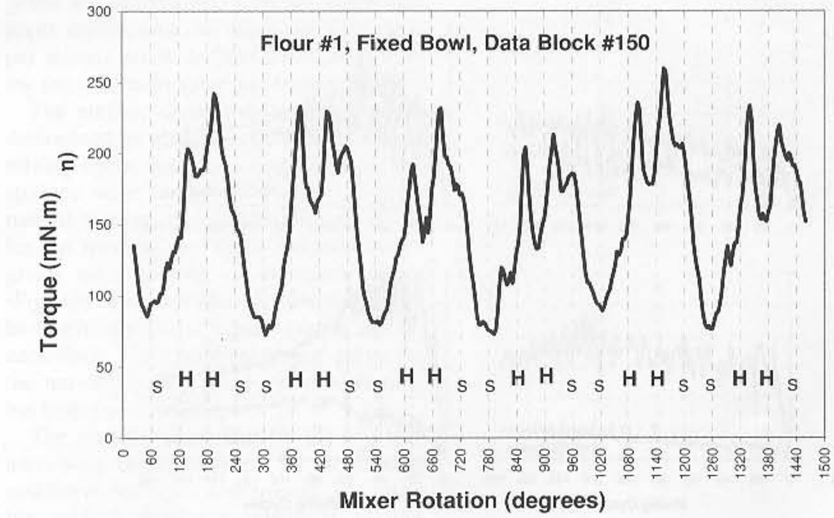

Fig. 6. Mixing data from mixing cycle 150.

RESULTS AND DISCUSSION

An electronic mixogram for hard wheat flour is shown in Fig. 5. The data was collected for 8 min or 176 mixing cycles. The upper two lines represent the average torque at each mixing cycle and 10-point smoothing of the average data. The lower lines represent the standard deviation at each mixing block and 10-point smoothing of the standard deviation data. The standard deviation per mixing cycle was used as the second dough response parameter, replacing the conventional mixogram bandwidth.

Figure 6 shows mixing cycle 150 from the same electronic mixogram. The six subcycles are readily apparent in the expanded mixogram data, similar to the subcycles in the simulation model by Steele and coworkers (9). Pairs of mixing pins straddle or hurdle the stationary bowl pins. Vertical lines have been labeled with either the letter s, denoting a straddle, or with the letter H, denoting a hurdle. When straddling, one pin passed outside and the other pin passed inside the bowl pin. When hurdling, both pins passed outside the bowl pin. Greater torque was developed and higher peaks produced during hurdles because both pins traveled at maximum velocities and distances from the center. Less torque was developed in the mixogram during straddles because one pin traveled at minimum velocities and distances from the center.

The illustrated valleys and peaks in Fig. 6 reveal why the method of data collection is important. If, for instance, data had been collected predominantly in the valleys, the recorded average torque would be lower than the true average. Additionally, if the data were collected out of synchronization with the cycles, the standard deviation could display harmonic fluctuations. Therefore, the best method of data collection is in synchronization with the mixing cycles.

Collection of sufficient points per mixing cycle is required for accurate analysis. The minimum number of points to coarsely describe a sine wave is four (2). As more points are added, the wave becomes more clearly described. The mixing waveform was not a sine wave and required many more than four points per subcycle to be identified clearly. Sixty points per subcycle or 360 points per mixing cycle were used to describe the mixing-response waveform for the data collected.

System Spring-Mass Response

Deflecting our 10-g fixed-bowl platform to a torque-transducer overload stop and then releasing it created the graph shown in Fig. 3. The shape of the spring-mass response is a dampened sinusoid. The response is similar to a tuning fork vibration.

The main characteristic of the spring-mass response is the time response for the platform to move from maximum to zero displacement. This is equal to one-fourth of the sine-wave response. The mixogram bandwidth is related to the spring-mass response time and the time between mixing actions. If the spring-mass response is faster than the mixing action, then the standard deviation will be at the maximum possible for the instrument. If the spring-mass response is slower, then the standard deviation will be less than the maximum because the mixer engages with the dough before the spring has settled.

The mixing-action rate is related to the number of hurdle and straddle events per second. A standard mixograph is set to operate at 88 rpm or 22 mixing cycles per minute, which converts to 2.72 sec per mixing cycle. Each mixing cycle contains six subcycles, and each subcycle contains two hurdles and two straddles, which converts to 24 mixing actions per mixing cycle. Thus, a single mixing event (hurdle or straddle) occurs every 0.114 sec.

Our fixed-platform instrument had a dampening sine-wave cycle time of 0.025 sec and a quarter-cycle time of 0.006 sec. The fixed instrument's spring response was much faster than the mixing input. Data collected from our moving-platform instrument yielded a dampening cycle time of 1.12 sec and a quarter-cycle time of 0.28 sec. Sequential mixing input occurred before the moving system's spring could pull the platform to the bottom of the chart and significant dampening occurred.

To estimate the amount of dampening that occurred with the moving system, the mixing-action rate was compared with the quarter-cycle response time of the moving system. The ratio was 0.114:0.28 or 0.41. The bandwidth of the moving system was estimated as 41% of the maximum possible bandwidth.

The mixogram bandwidth is the maximum torque minus the minimum torque for each mixing cycle. The average of the data is commonly determined along with the standard deviation of the data. Standard deviation correlates directly with bandwidth and is roughly the bandwidth divided by four.

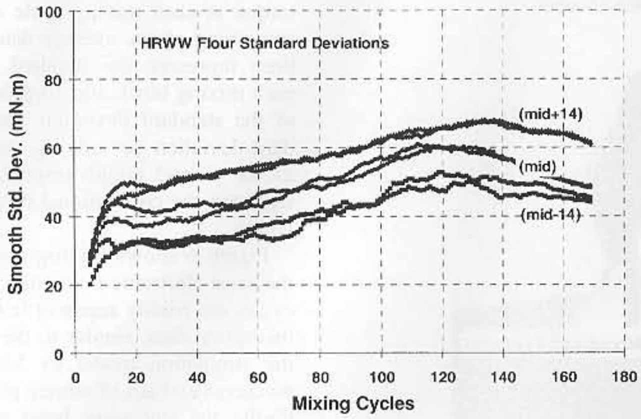

Fig. 7. Standard deviation responses from three bowl positions.

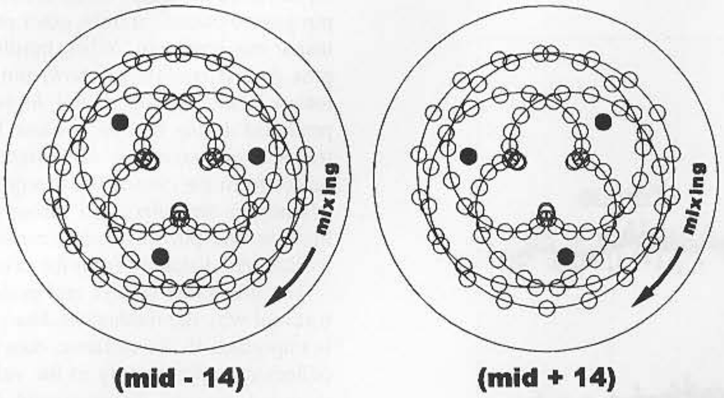

Fig. 8. Bowl pin positions compared with mixing path.

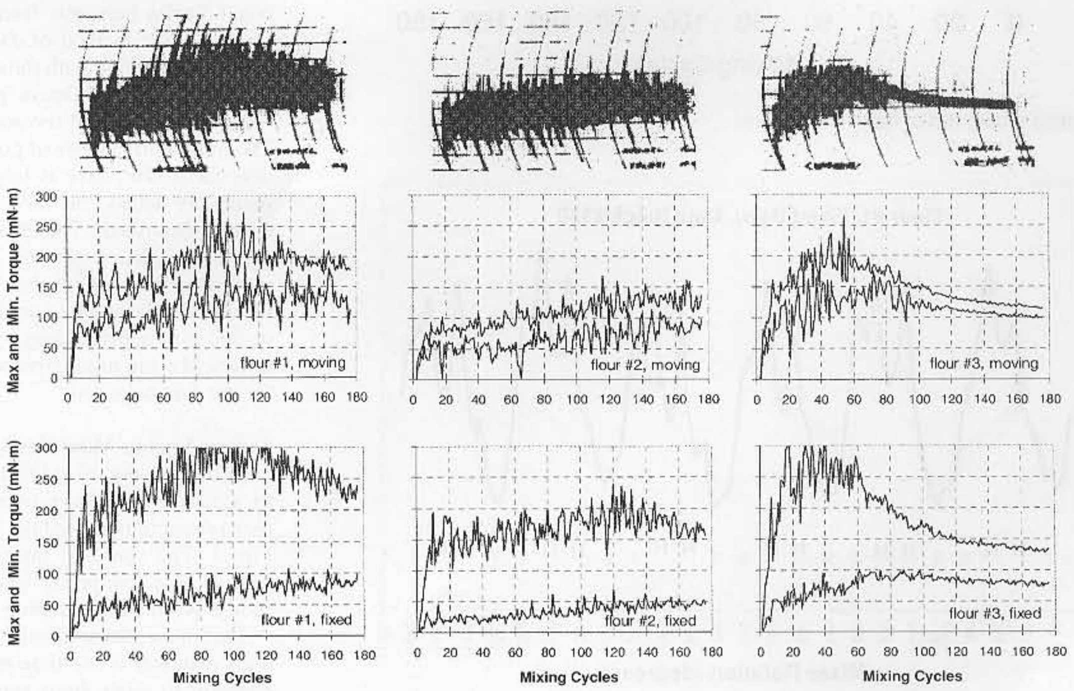

Fig. 9. Traditional, moving-bowl, and fixed-bowl mixograms for three flours.

The standard deviation data from the moving system was compared with the standard deviation data from the fixed system for the flours tested. The average of the moving and fixed deviations was 0.47 for the three flours, each with 176 mixing cycles, which was reasonably close to the 0.41 multiplier.

Effect of Varied Bowl Pin Position

Three bowl positions were tested with a hard red wheat (HRW) flour and a soft red wheat (SRW) flour. The data show that the standard deviation of the mixogram was related to the bowl position for both the HRW and SRW flours. The standard deviation responses were highest at +14° and lowest at –14° (Fig. 7).

The torque responses were not the same for the HRW and SRW flours. For the HRW flour, the smoothed torque response was highest for the midposition, and the –14° position produced the second highest torque response. For the SRW flour, the torque responses were similar for the three positions, except at the –14° position, at which the torque response was higher during the first few minutes of mixing.

When considering the movement of the mixing pins and the dough relative to the bowl pins, a position near –14° maximized the space of the oncoming mixing pins (Fig. 8). The extra space and time allowed the interactions between the dough and fixed instrument to be less variable.

Mixogram and Standard Deviation Curves

Mixograms from three distinctly different flours are shown in Fig. 9. The curves in the top row were made with the 10-g, traditional moving-bowl instrument, using pen and ink and chart paper. The middle row of mixograms was made with the 10-g, moving-bowl electronic instrument, and the bottom row was made with the fixed-bowl electronic instrument. The chart and pen mixogram contains arcing lines from the swinging system. The electronic mixograms are summarized with two lines—the upper representing the maximum data value per mixing block and the lower representing the minimum value per mixing block.

The midline of the mixograph data was determined by averaging the torque at each mixing cycle, and the averaged torque responses were smoothed with a 10-point running average. The smoothed torque curves for the moving- and fixed-platform mixograms were plotted for the three flours (Fig. 10). The smoothed torque appears to be nearly identical for both systems and for each flour. The smoothed torque curve for the moving system shows more variation, but both curves overlap.

The standard deviations for the two systems were visibly different for the moving and fixed electronic instruments. The moving system exhibited relatively smaller standard deviations, as represented by the lower charts (Fig. 10). The fixed system produced the maximum standard deviation possible because its spring-mass response was faster than the mixing-action time. The standard deviation curve for the fixed system was modified with a single multiplier to match the moving standard deviation data. The multiplier was estimated earlier as 0.41 based on the ratio of the mixing-action time to the full-scale response time of the moving system.

In this case, the standard deviations for the fixed system were modified to appear like those of the moving system, because many mixograph users are familiar with the bandwidths from moving systems. However, the moving deviations could be modified to appear like the fixed. The fixed standard deviations represent the maximum deviation possible, and the slopes of the fixed standard deviation curves are more dramatic.

The smoothed torque and normalized standard deviation plots were sufficient to characterize dough responses for both moving- and fixed-bowl instruments. The torque curve provided dough-mixing information separate from the standard devia-

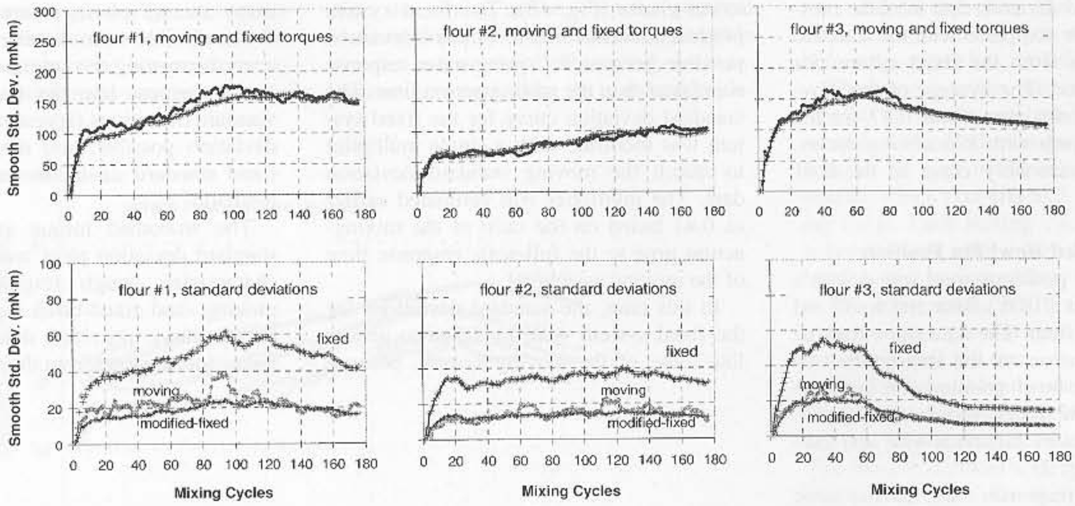

Fig. 10. Smoothed torque and standard curves for three flours.

tion curve. Separating the torque response and the standard deviation response aided in distinguishing differences between flours.

For example, flour 1 and flour 2 exhibited similar standard deviation responses; however, their smoothed torque responses were significantly different. The smooth torque curve for flour 3 demonstrated strength similar to flour 1, but the standard deviation response for flour 3 exhibited significant reductions at the tail. For Fig. 10, the scale of the torque charts was 0–300 mN·m, while the scale for the standard deviation charts was 0–100 mN·m.

SUMMARY

Several important features emerged from this study. Measuring mixograph response as torque rather than chart paper position would facilitate a standardization procedure between instruments and comparison of different flours. The existence of six subcycles within a mixing cycle of 1,440° demonstrates the presence of machine harmonic activity. Data acquisition methods need to account for the peaks and valleys of the machine harmonic, and one method is to synchronize data collection within the mixing cycles. Second, the data acquisition system needs to acquire an adequate number of points to accurately represent mixing cycles.

Because there were differences in the spring and mass characteristics, the standard deviations for the fixed system were significantly larger than the deviations for the moving system. Basic methods for determining the time responses of mixograph systems were given for both the moving and fixed systems. The fixed system used a stiffer spring, which responded to a full-scale change in torque in 0.006 sec. The moving systems responded to a full-scale change in torque in 0.28 sec.

The reference point for the standard deviation should be established by the users. In this study, the fixed-platform standard deviation data was modified with a dampening ratio of 0.41. Applying this dampening ratio to the fixed-platform deviations produced standard deviation responses similar to the moving-platform deviations. This was done to accommodate users of moving systems. However, it is our opinion that the reference for standard deviation should be the fixed system, because the fixed system represents the maximum deviation values and appears to accentuate differences between standard deviation responses.

The effect of bowl pin positions was studied for the fixed system. The standard deviation responses were related to the bowl pin position for both the HRW and SRW flours. The standard deviation response was lowest at the −14° bowl position. The torque responses were not the same for the HRW and SRW flours and varied more with the HRW flour than with the SRW flour.

The smoothed torque data and normalized standard deviation matched for both the moving- and fixed-bowl systems. The basic mixing characteristics of several doughs were described adequately by the smoothed torque and normalized standard deviation. With electronics, mixograms are moving away from a bandwidth of ink on a chart, as produced with a moving system, toward digital data processing and a fixed system. In this study, digitally processing mixograms into separate torque and standard deviation responses aided in distinguishing and evaluating differences between flours tested.

Acknowledgments

We thank J. Steele for his significant input and suggestions on this work.

References

1. AACC Method 54-40A, Mixograph Method. *Approved Methods of the American Association of Cereal Chemists*, 10th ed. The Association, St. Paul, MN, 2000.
2. Carlson, G. E. Spectra of discrete-time signals. In: *Signal and Linear System Analysis*. John Wiley & Sons, New York, 1992.
3. Finney, K. F., and Shogren, M. D. A ten-gram mixograph for determining and predicting functional properties of wheat flour. Baker's Dig. 46(2):32, 1972.
4. Gras, P. W., Carpenter, H. C., and Anderssen, R. S. Modelling the developmental rheology of wheat-flour dough using extension test. J. Cereal Sci. 31:1, 2000.
5. Meriam, J. L. Vibration and time response. In: *Dynamics*. John Wiley & Sons, New York, 1975.
6. Navickis, L. L., Butterfield, R. O., and Nelsen, T. C. A modified electronic torsion sensor for a 10-g mixograph. Cereal Chem. 66:350, 1989.
7. Rubenthaler, G. L., and King, G. E. Computer characterization of mixograms and their relationship to baking performance. Pages 131-167 in: *Fundamentals of Dough Rheology*. H. Faridi and J. Faubion, eds. Department of Grain Science and Industry, Kansas State University, Manhattan, 1986.
8. Shogren, M. D. A short history of the mixograph. Cereal Foods World 35:480, 1990.
9. Steele, J. L., Brabec, D. L., and Walker, D. E. Mixograph instrumentation for moving-bowl and fixed-bowl comparisons of wheat flour performance. Proc. Food Proc. Automation Conf. American Society of Agricultural Engineers, St. Joseph, MI, 1990.
10. Voisey, P. W., Miller, H., and Kloek, M. An electronic recording dough mixer. Cereal Chem. 43:408, 1966.
11. Walker, C. E., and Walker, A. E. Mixograph data acquisition and analysis by personal computer. Cereal Foods World 35:823, 1990.
12. Wooding, A. R., and Walker, C. E. Comparison of alternative recording mechanisms (mobile vs. fixed-bowl) for the 35- and 10-gram mixographs. Cereal Chem. 69: 249, 1992.