A MILL DESIGN CONCEPT FOR REDUCING BAGASSE MOISTURE

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Abstract

THIS PAPER DESCRIBES the development and testing of a novel mill design to reduce the moisture content of bagasse. It takes advantage of gravity to separate juice from bagasse by pushing bagasse upwards while juice drains downwards under gravity. The potential of the design to reduce bagasse moisture content has not been adequately established. The prototype mill had limited power available that prevented typical delivery nip compactions from being achieved. Tests conducted did show a reduction in bagasse moisture but that moisture reduction is less than expected under ideal conditions. Work on the mill design has ceased, at least for the foreseeable future. The design does have potential to reduce bagasse moisture content but presents some engineering challenges to establish a reliable, low maintenance design alternative.

Introduction

As discussed by Kent *et al*. (2012), the reduction in bagasse moisture content remains an attractive objective for raw sugar factories. In an effort to reduce bagasse moisture content, a concept first demonstrated by Kauppila and Loughran (2000) has been further explored. This concept involves feeding bagasse upwards to take advantage of gravity as a means of separating juice from bagasse. Kent *et al*. (2012) described the experimental investigation to explore these concepts and concluded that bagasse moisture content could be reduced by more than two units by feeding bagasse upwards at an angle of 50° to the horizontal.

This paper discusses the investigation to convert the basic concept into a mill design called *the dewatering mill*.

A design concept to feed bagasse upwards

The original concept to enable bagasse to be fed upwards was developed by Mr Ralph Dephoff of New South Wales Sugar Milling Co-operative Limited. The concept is shown in Figure 1. In Figure 1, the mill pressure feeder is to the right of the drawing and the top and delivery rolls of the mill are labelled ‘B’ and ‘A’ respectively.

The design concept is to install a further pair of rolls called *dewatering rolls* ‘G’ and ‘H’ after the delivery nip. A pressure feeder chute called the *dewatering chute,* ‘I’, is fitted to the delivery nip of the mill to feed the bagasse upwards into the dewatering mill.

A prototype dewatering mill

A collaborative effort by the New South Wales Sugar Milling Co-operative Limited, Bundaberg Foundry Engineers Limited (now Bundaberg Walkers Engineering Limited) and the Sugar Research Institute resulted in a prototype dewatering mill being fitted to the 1830 mm final mill at Harwood factory. The dewatering rolls had outside diameters of 950 mm, groove pitch of 38 mm and groove depth of 53 mm.

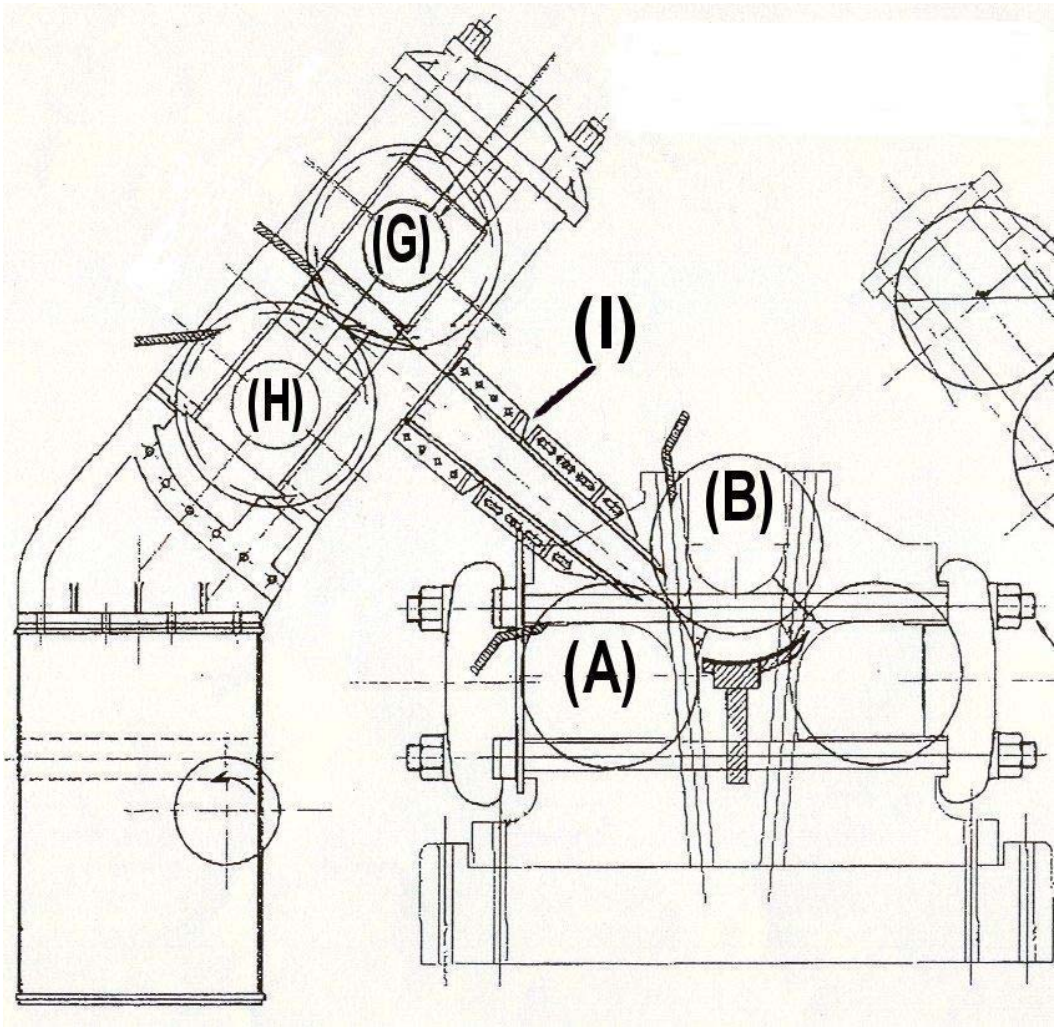

Fig. 1—Concept drawing of the dewatering mill.

The dewatering mill cheeks had been purchased second-hand by the Co-operative, following the closure of Cattle Creek Mill some years previously. New rolls were provided by Bundaberg Foundry. Two 90 kW electric motors, variable frequency drive controllers and shaft-mounted gearboxes were purchased from Brevini Australia Pty Ltd to drive the dewatering rolls. The remainder of the construction was conducted in-house by Harwood factory staff.

Figure 2 shows the dewatering mill in its completed state, just before the start of the 2005 crushing season.

Operating experience

The 2005 season

The mill failed after about ten hours of operation at the start of the 2005 season. The failure was caused by the detachment of the dewatering chute top plate from the chute side plates and its subsequent relocation from under the top roll to on top of the top roll. This movement caused the dewatering chute to converge rather than diverge and restricted bagasse flow into the dewatering nip which ultimately caused the mill to push the dewatering mill off its foundations.

The cause of the chute plate detachment was attributed to shearing of the bolts on the keeper plates (Figure 3). It is believed that the bolts were loaded unevenly causing a gradual failure of one bolt after another as each bolt was individually loaded beyond its shear strength.

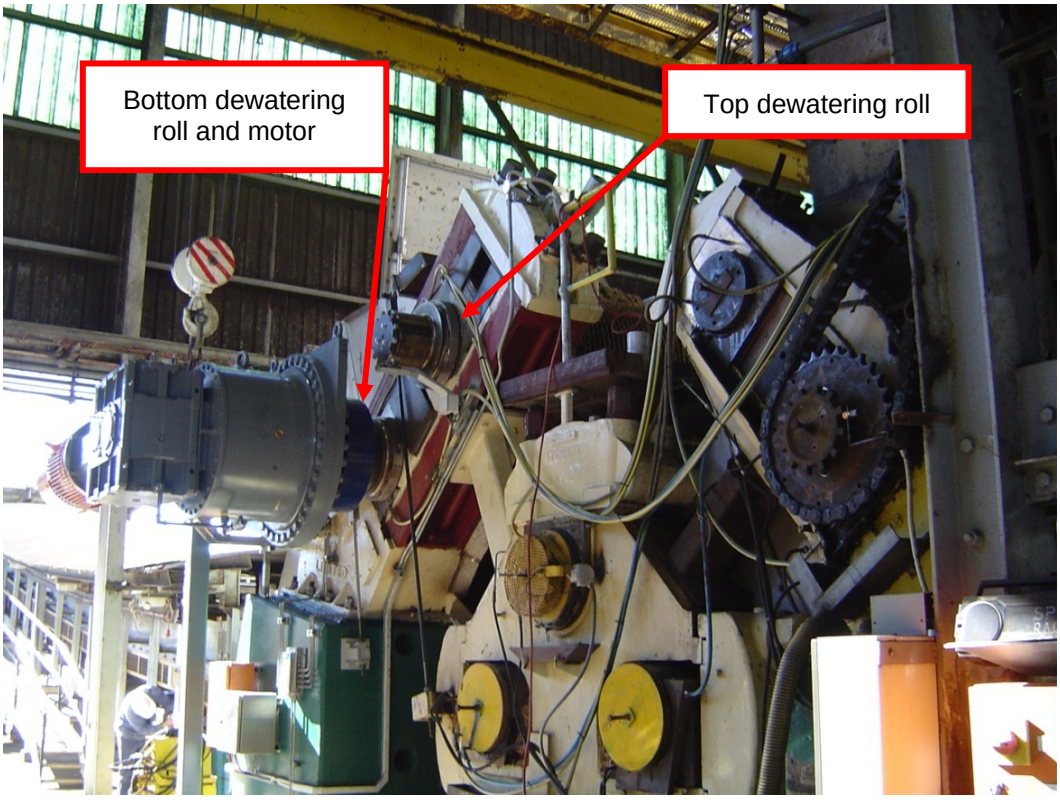

Fig. 2—The completed dewatering mill prior to the start of the 2005 crushing season.

Fig.3—The bottom chute plates and keeper plates still in position after the failure. Note in the second photograph, the bolts have sheared and are missing, just like in the failed top plates.

Damage to the dewatering mill foundations prevented the repair of the mill during the 2005 season and so further testing was delayed until the 2006 crushing season.

The 2006 season

The mill suffered three further, but relatively minor, failures in the first several days of crushing in the 2006 season. The first failure involved deformation of a dewatering roll scraper plate. The second and third failures involved failure of the dewatering mill motor torque arm foundations. In all cases, the failed components were redesigned and strengthened. No further failures were experienced.

To reduce the risk of further failures, the dewatering mill operated for most of the season at very low load. Approval was given to increase the load on the mill in December 2006. After several days of trials where the load was incrementally increased, the mill was operated at its design torque of 500 kN.m (for both rolls) most day shifts (12 hour shifts) through the final three weeks of the season.

The 2007 season

After being lightly loaded for the first five weeks of the 2007 season, the mill was operated at its design torque for 14 weeks before a second catastrophic failure occurred. The failure involved the chute parting from the mill side plates and the mill cheeks, and moving forward.

Displacement sensors fitted to the chute detected the movement and the control system stopped the mill before irreparable damage occurred. Following the repair of the mill, it was operated in a lightly loaded fashion for the remainder of the season.

The 2008 season

The dewatering mill was operated at its design torque for a total of 21 weeks during the 2008 season, starting in the second week of the season. About two weeks before the end of the crushing season, the dewatering mill suffered a significant failure involving a further movement of the dewatering chute. Several attempts to repair the mill failed and the mill was eventually bypassed for the remainder of the season.

Comments

The dewatering mill was operated at its design torque for most of two seasons, providing an opportunity to evaluate its performance.

Three significant dewatering chute failures occurred over the life of the mill. These failures all point to high loads in the dewatering chute and inadequate designs for fixing the top and bottom chute plates to the side plates and for fixing the chute to the mill cheeks. These design issues can all be overcome and most were overcome.

The prototype testing was halted after the 2008 season so that a more detailed experimental investigation could be undertaken to measure the size of forces in pressure feeder chutes and hence better determine the design loads for the dewatering mill chute.

Changing priorities for the project participants caused funding for this investigation to be halted before the experimental investigation could be completed.

Mill performance

Routine performance

Table 1 presents operating and performance parameters for the dewatering mill during the 2007 and 2008 seasons when the dewatering mill was operating at its design torque set point of 500 kN.m.

Table 1—Routine operating and performance parameters

Season	Fibre rate (t/h)	Nip compaction (kg/m^3)		Dewatering mill torque (kN.m)	Bagasse moisture content (%)
		Delivery	Dewatering		
2007	35.0	1027	691	443	49.5
2008	33.9	1422	815	423	49.0

Although the dewatering mill torque was close to its set point, the dewatering nip compaction was substantially less than expected, indicating that the design torque set point was originally underestimated.

The 2008 delivery nip compaction result of 1422 kg/m^3 is not believed to be a true measurement. One of the difficulties associated with the presence of the dewatering mill is the lack of access to measure the delivery nip setting. The 1422 kg/m^3 value is based on a best estimate of the setting during the season but, when the mill was dismantled at the end of the season, the setting was found to be somewhat greater than the estimated measurement.

It was unfortunate that the compaction achieved in the dewatering nip was substantially less than the compaction achieved in the delivery nip. Because the bagasse had already been compressed to a greater compaction in the delivery nip, the removing of appreciably more juice with a lower compaction in the dewatering nip was unlikely.

Effect of dewatering mill on bagasse moisture content

The best opportunity to determine the performance benefit of the dewatering mill was obtained at the end of the 2006 crushing season when the dewatering mill was operated at its design torque during most day shifts and was operated at very low load during the remaining shifts. This period included 12 shifts with the dewatering mill operated at its design torque and 16 shifts with the dewatering mill operated at low torque.

Figure 4 summarises the results in box-plot form. Each box plot presents a summary of all of the test data at the identified torque condition. The white line through the centre of each box is located at the median value. The coloured box contains half of the results. The horizontal line above and below the box represents the maximum and minimum test value, respectively. The median values are summarised in Table 2.

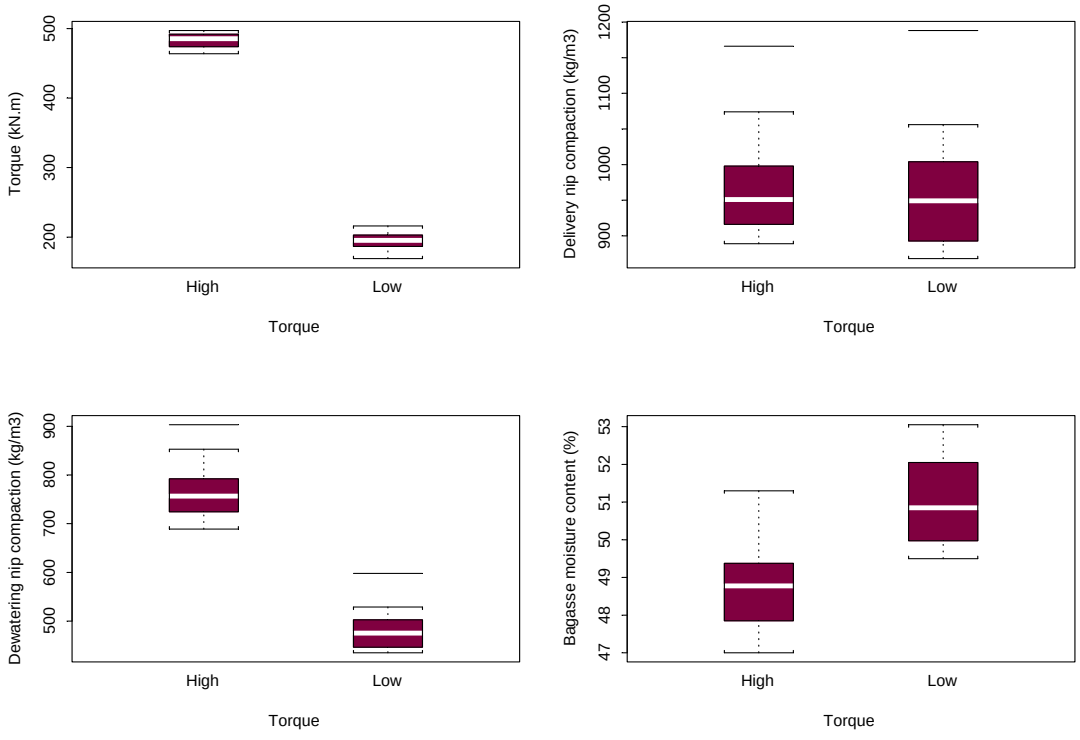

Fig. 4—Results of the mill performance comparison between operating the dewatering mill at high torque and low torque.

Table 2—Median parameter values from the mill performance comparison

Parameter	Torque condition	
	Low	High
Dewatering mill torque (kN.m)	196	486
Delivery nip compaction (kg/m^3)	949	951
Dewatering nip compaction (kg/m^3)	476	757
Bagasse moisture content (%)	50.9	48.8

Figure 4 and Table 2 show that the dewatering mill torque was substantially different for the two torque conditions, causing a statistically significant difference in the dewatering nip compaction and a statistically significant difference in the bagasse moisture content.

The bagasse moisture content was 2.1 units lower with the dewatering mill operating at its design torque. Visual inspection during the period confirmed that there were no indications of juice being expressed from the dewatering nip during the low torque periods but that some juice could be observed from the dewatering nip during the high torque periods.

A designed experiment

To gain further information about the performance characteristics of the dewatering mill, an experiment was conducted. The experiment measured the effect of two factors on the performance of the dewatering mill: mill torque and dewatering mill torque. Varying the mill torque varies the moisture content of the feed bagasse to the dewatering mill. Varying the dewatering mill torque varies the dewatering nip compaction.

The experiment was conducted as a randomised block experiment. Tests were conducted in blocks of four, with each block containing a factorial experiment involving two levels of mill torque (total of the three mill rolls) and dewatering mill torque (total of the two dewatering rolls), a total of 16 tests. The levels of torque examined in the experiment are listed in Table 3. The order of tests within a block was selected randomly.

Table 3—Levels of each factor explored in the experiment.

Factor	Level 1	Level 2
Mill torque (kN.m)	650	850
Dewatering mill torque (kN.m)	400	500

Figure 5 shows that good differentiation was achieved between the factor levels. The graphs show the average value of the parameter at each factor level. For example, the graph on the left hand side shows the average mill torques.

It shows that the average mill torque when the mill torque was set to 850 kN.m was a bit less than 800 kN.m. In comparison, the average mill torque did not vary much at all across the two dewatering mill torque levels.

Figure 6 shows a summary of the bagasse moisture content results. While the results show that bagasse moisture content was lower with higher mill torque and higher dewatering mill torque, an analysis of variance found that only the mill torque effect was statistically significant. The result is believed to be a consequence of the relatively high mill torque compared to the dewatering mill torque as a result of the limited size of the dewatering mill drives.

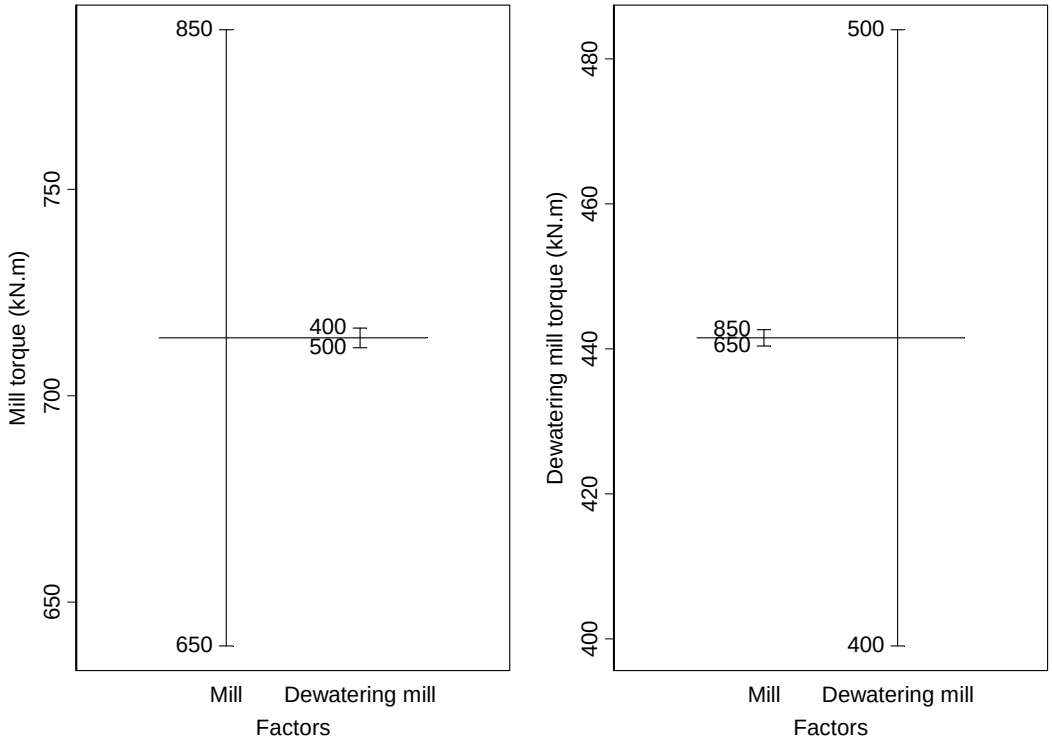

Fig. 5—Achievement of factor levels in performance experiment.

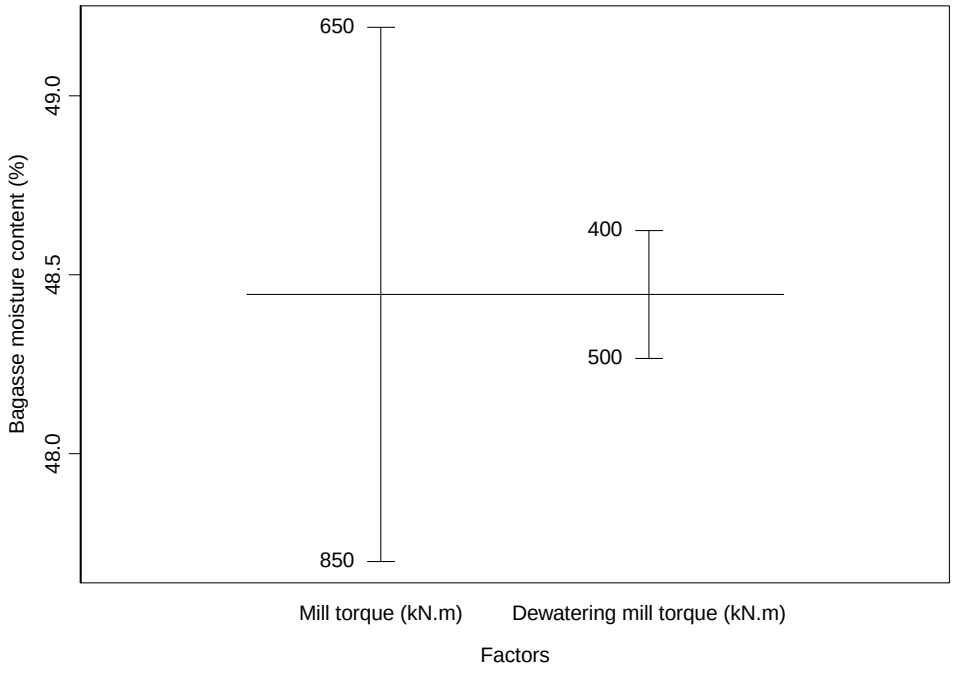

Fig. 6—Bagasse moisture content results from performance experiment.

Concluding remarks

Performance results have shown that the dewatering mill does provide a reduction in bagasse moisture content. The best experimental results suggest that a reduction of 2.1 units of moisture was achieved with the dewatering mill in operation.

The true benefit is likely to be a less than that because a certain amount of mill torque is consumed in pushing bagasse through the dewatering chute rather than in compressing bagasse in the delivery nip. The 2.1 unit reduction in bagasse moisture content was achieved with the dewatering mill in position but operating at very low torque.

It is possible that lower moisture content would have been achieved without the dewatering mill if the dewatering chute had been removed, but such a task was not possible within the scope of the experiment.

The biggest impediment to properly assessing the performance of the dewatering mill was the inability to achieve delivery nip size compactions in the dewatering nip, because of the limited size of the dewatering mill drives. Because the delivery nip was able to achieve much higher compactions than the dewatering nip, the true benefit of the dewatering mill could not be experimentally assessed.

Mill control

Total dewatering mill torque control

The final mill at Harwood factory was typically configured to control chute level by varying pressure feeder speed and to control mill torque by varying the pressure feeder to mill ratio (that varied the mill speed relative to the pressure feeder speed).

Kent *et al*. (2004) described this control system in detail. When the dewatering mill was installed, this control approach was extended so that the dewatering mill torque was controlled by varying the ratio of the mill speed to the dewatering mill speed (that varied the dewatering mill speed relative to the mill).

The more conventional approach of controlling chute level by varying mill speed and using pressure feeder speed to vary the pressure feeder to mill ratio to control mill torque was also tested. With this configuration, dewatering mill torque was still controlled by varying the dewatering mill speed.

An experiment was conducted to determine which control strategy gave more consistent dewatering mill torque. The experiment was conducted in blocks of two tests, with each block consisting of a test using the *PF* system (with chute level controlled by pressure feeder speed) and a test using the *Mill* system (with chute level controlled by mill speed).

A total of 16 blocks of tests were completed. In all tests, the mill torque set point was 720 kN.m and the dewatering mill torque set point was 500 kN.m.

The duration of each test was one hour and mill torque and dewatering mill torque were recorded every two seconds. Each test was assessed by calculating the variance and maximum value (as a ratio to the set point) of both mill torque and dewatering mill torque.

The results are summarised in Figure 7. The mill torque variance, the mill torque maximum value and the dewatering mill torque variance were all lower when using the *Mill* control system (with chute level controlled by mill speed).

The mill torque variance and maximum value differences were statistically significant. There was no difference in the maximum value results for the dewatering mill torque.

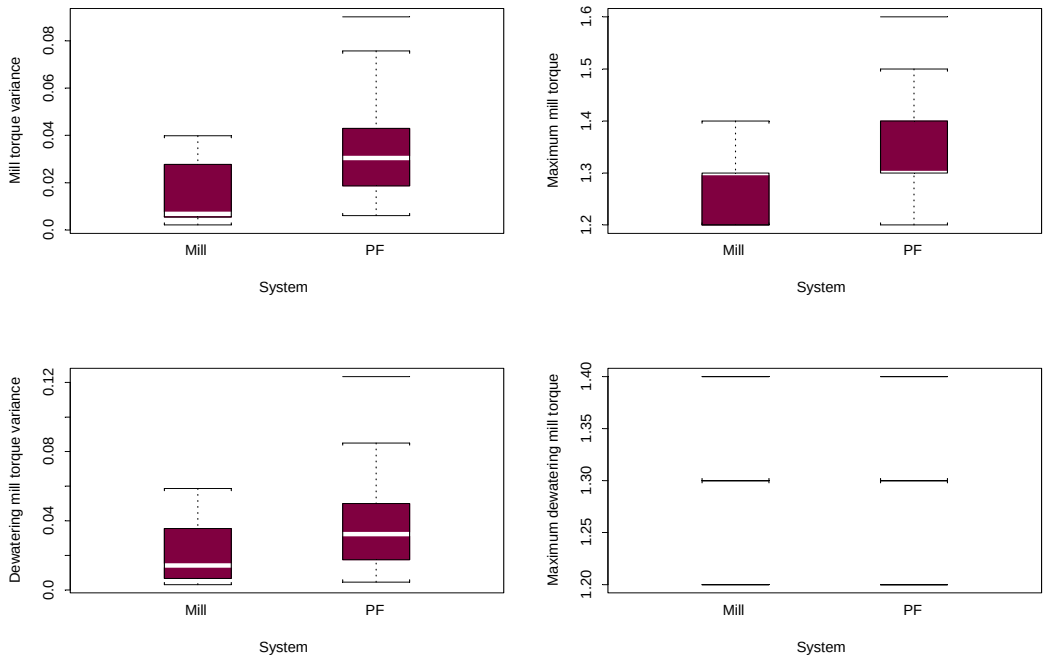

Fig. 7—Results of the control system comparison experiment.

Dewatering roll torque control

With two independently driven dewatering rolls, the torque on each roll was generally not the same. This problem has been previously reported by Crouther *et al*. (1999). To balance the torques, the bottom dewatering roll torque was controlled by the bottom dewatering roll speed (relative to the top dewatering roll speed).

Concluding remarks

The conventional control strategy for mills with independently driven pressure feeders, with chute level controlled by mill speed, worked better in combination with the dewatering mill control strategy of varying dewatering mill torque with dewatering mill speed than the alternative strategy of controlling chute level with pressure feeder speed.

The approach of varying the bottom dewatering roll speed to balance the torque on the two dewatering rolls was effective.

Maintenance issues

The presence of the dewatering mill had some implications for routine maintenance.

The nose plates from the dewatering chute on the top and delivery rolls needed adjusting each maintenance stop. While the adjustments were being made, the mill rolls could not be arced. The design for the adjustment was modified before the 2008 season to enable this process to be undertaken quickly and easily.

During the 2007 season, it was not possible to arc the bottom dewatering roll or delivery roll when crushing. Before the 2008 season, a platform was built to enable the bottom dewatering roll to be arced. Access to the delivery roll was also arranged.

As discussed earlier, it was difficult to measure the delivery nip setting. At the completion of the testing program in 2008, no satisfactory system to measure the setting had been established.

Conclusions

The potential of the dewatering mill design to reduce bagasse moisture content has not been satisfactorily established through measurement. Both the two-roll mill experiments reported by Kent *et al*. (2012) and the prototype tests conducted at Harwood factory had limited power available that prevented delivery nip size compactions from being achieved in the dewatering nip. Tests conducted on the prototype mill did show a reduction in bagasse moisture when the dewatering mill was operated at its design torque but that moisture reduction was less than expected under ideal conditions.

Forces in the dewatering chute are much larger than forces in a conventional pressure feeder chute, presumably as a result of the greater torque available in the delivery nip to push bagasse through the chute and the drier bagasse coming out of the delivery nip. The size of these forces has not been conclusively established.

Satisfactory mill control was achieved by using a conventional strategy for controlling the mill with its independent pressure feeder, using dewatering mill speed to control dewatering mill torque and using the bottom dewatering mill speed to balance the torque on the two dewatering rolls.

The presence of the dewatering mill presented some maintenance challenges in enabling easy adjustments of the nose plates on the top and delivery rolls, arcing the delivery and bottom dewatering mill rolls and measuring the delivery nip setting. Most of these challenges have been overcome.

Work on the dewatering mill design has ceased, at least for the foreseeable future. The design does have potential to reduce bagasse moisture content but presents some engineering challenges to establish a reliable, low maintenance design alternative.

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