REFEREED PAPER

AN ALTERNATIVE APPROACH TO SETTING A MILL

KENT GA

Queensland University of Technology, GPO Box 2434, Brisbane, Queensland, 4001, Australia
g.kent@qut.edu.au

Abstract

The conventional approach to setting a milling unit is essentially based on the desire to achieve a particular bagasse moisture content or fibre fill in each nip of the mill. This approach relies on the selection of the speed at which the mill will operate for the selected fibre rate. There is rarely any checking that the selected speed or the selected fibre fill is achieved and the same set of assumptions is generally carried over to use again in the next year.

The conventional approach largely ignores the fact that the selection of mill settings actually determines the speed at which the mill will operate. Making an adjustment with the intent of changing the performance of the mill often also changes the speed of the mill as an unintended consequence.

This paper presents an alternative approach to mill setting. The approach discussed makes use of mill feeding theory to define the relationship between fibre rate, mill speed and mill settings and uses that theory to provide an alternative means of determining the settings in some nips of the mill. Mill feeding theory shows that, as the feed work opening reduces, roll speed increases. The theory also shows that there is an optimal underfeed opening and Donnelly chute exit opening that will minimise roll speed and that the current South African guidelines appear to be well away from those optimal values.

Keywords: sugar mill, sugar mill setting, speed, rate, compaction, feeding

Introduction

Mill setting is an important process that is undertaken on each milling unit every year for the purpose of operating the mill to achieve satisfactory performance. It is necessary to select the opening between each pair of rolls in a mill and also to select the opening in the Donnelly chute feeding the mill.

This paper reviews the existing mill setting methods used in South Africa and introduces the concept of mill feeding theory to overcome the limitation that the method relies on the selection rather than prediction of roll speed.

Existing practice

Discharge work opening

As documented by Wienese (1990), two methods have been adopted in South Africa to determine mill settings: the *Natal* method and the *Australian* method.

Using the Natal method, Wienese (1990) reports that the delivery work opening (K_d, in mm) is calculated from equation 1:

$$K_d = \frac{286 \times 10^4 \; C \; F}{D \; L \; N \; B} \tag{1}$$

where C is the cane rate (t/h)
F is the cane fibre content (%)
D is the mean roll diameter (mm)
L is the roll length (mm)
N is the roll speed (r/min)
B is the bagasse fibre content (%).

Using the Australian method, Wienese (1990) reports that the delivery work opening is calculated from equation 2:

$$K_d = \frac{5305 \times 10^4 \; C \; F}{D \; L \; N \; F_d} \tag{2}$$

where F_d is the fibre fill at the delivery opening (kg/m^3). Fibre fill is called *compaction* in Australia and is defined as the mass of fibre per unit volume.

Wienese (1990) comments that the Natal and Australian methods are very similar. Comparing equations (1) and (2) results in equation 3:

$$F_d = \frac{5305}{286} B \tag{3}$$

Equation (3) is presented graphically in Figure 1 for the typical range of values used in the mill setting process. The Natal and Australian methods are essentially the same. In the Natal method, it is necessary to know a suitable bagasse fibre content value to select the correct delivery work opening. In the Australian method, it is necessary to know a suitable fibre fill to select the correct delivery work opening.

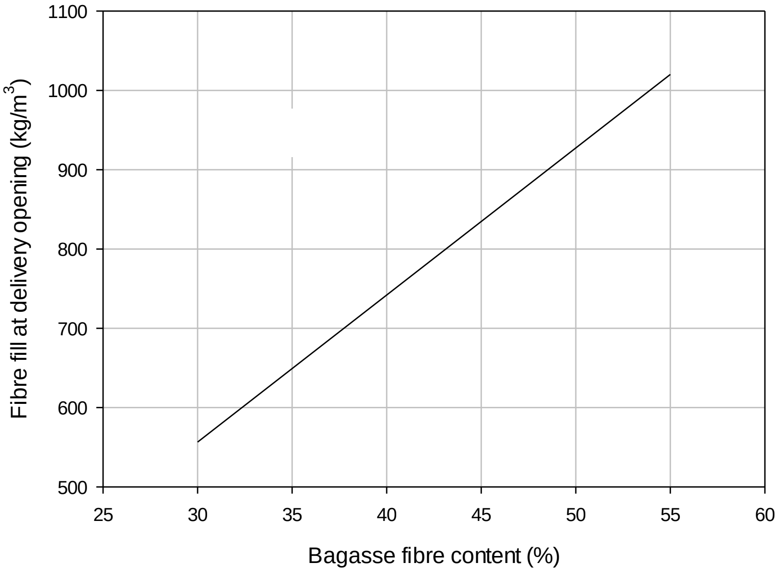

Figure 1. Relationship between bagasse fibre content and fibre fill used to determine delivery work opening.

Feed work opening

Using the Natal method, Wienese (1990) reported that the feed work opening (K_f, in mm) is calculated from:

$$K_f = K_d\, R \tag{4}$$

where R is the feed to delivery work opening ratio.

Using the Australian method, Wienese (1990) reported that the feed work opening is calculated from:

$$K_f = \frac{5305 \times 10^4\, C\, F}{D\, L\, N\, F_f} \tag{5}$$

where F_f is the fibre fill at the feed opening (kg/m^3).

Substituting equations (2) and (5) into equation (4):

$$R = \frac{K_f}{K_d} = \frac{F_d}{F_f} \tag{6}$$

In other words, selecting a ratio of feed to delivery work opening as used by the Natal method is the same as selecting a ratio of fibre fills for the delivery and feed openings. This latter approach is more commonly used by Australian milling engineers. While some Australian milling engineers use F_d in equation (5) directly, it is more common to calculate F_d from:

$$F_f = \frac{F_d}{R} \tag{7}$$

Underfeed work opening and Donnelly chute opening

To completely define the behaviour of the mill, it is also necessary to specify the underfeed work opening and the Donnelly chute exit opening. The trash plate opening also needs to be determined but is not relevant to the topic of this paper.

Wienese (1995) indicates that the underfeed work opening and the Donnelly chute exit opening are calculated using a work opening ratio similar to that used for the feed work opening in equation (4). For mills with pressure feeders, a similar ratio is also defined. Equations to calculate the pressure feeder work opening (K_p), the underfeed work opening (K_u) and the Donnelly chute exit opening (K_e) can be presented as:

$$K_p = K_d\, R_p \tag{8}$$

$$K_u = K_d\, R_u \tag{9}$$

$$K_e = K_d\, R_e \tag{10}$$

where R_p is the pressure feeder to delivery work opening ratio
R_u is the underfeed to delivery work opening ratio
R_e is the Donnelly chute exit to delivery work opening ratio.

Comments on existing practice

Introductory remarks

Referring back to equations (1) and (2), to calculate the delivery work opening for the next season, it is necessary to know values for the cane rate, cane fibre content, roll diameter, roll length, roll speed and either bagasse fibre content or fibre fill.

The desired cane rate is generally determined by factory management based on the estimate of crop size, desired season length and an estimate of factory availability. The cane fibre content can be estimated from historical cane fibre content data. The roll diameter and roll length are measurements of mill roll size. These values pose little difficulty.

Selecting the bagasse fibre content or fibre fill

The selection of the correct bagasse fibre content or fibre fill is often based purely on the value used during the mill setting process the previous year. While this process is widely used globally, it is less than ideal since it does not relate to actual operating conditions. As stated by Wienese (1995), the important point is that the mill lifts, or more precisely, that the hydraulically loaded rolls lift. To be more precise again, it is not so much important that the rolls lift as it is that the maximum allowable roll load is obtained. When a roll lifts, the roll load is controlled by the selection of hydraulic pressure on the roll.

Russell and Murry (1968) indicated that roll load is essentially proportional to fibre fill so that, as fibre fill increases, roll load increases. As concluded by Jayes (1994), low bagasse moisture content and hence high extraction is achieved with high fibre fill values, and hence high roll loads. There exists an optimal value of roll load that achieves the highest possible extraction with minimal risk of damage to the mill. Since fibre fill is related to roll load, knowing the fibre fill value that will achieve that optimal value of roll load enables a delivery work opening to be selected that will allow a roll to lift and hence the optimal roll load to be achieved.

History is the best guide to the fibre fill value that achieves the optimal value of roll load. If the hydraulic pressure was set to the maximum acceptable value and the hydraulically loaded rolls were floating, the fibre fill being achieved will be the value that should be used to determine the delivery work opening for the next season. To calculate that fibre fill value, equation (2) can be rearranged as shown in equation 11:

$$F_d = \frac{5305 \times 10^4 \; C \; F}{D \; L \; N \; K_d} \tag{11}$$

Equation (11) can be used on the previous season’s results to determine the desired fibre fill values.

Selecting the roll speed

The final parameter required to use equations (1) or (2) is the roll speed. As for the bagasse fibre content or fibre fill, it is common practice globally to simply use the value that was used the previous year.

An alternative approach is to use the actual value achieved the previous year, as determined for use in equation (11). This alternative approach is quite acceptable provided that the cane fibre rate required in the coming season will be the same as that achieved in the last season and that no major changes to the mill geometry are planned.

A common misconception is that, when a change in roll speed is desired, it can be achieved by simply changing the speed used in equations (1) or (2). This approach simply causes the wrong work openings to be selected.

A better approach is to acknowledge that the selection of mill settings actually controls the roll speed and to use mill feeding theory, such as presented by Kent (2004), to predict the correct roll speed for use in equations (1) or (2).

Predicting mill speed

Kent (2004) described a mill feeding theory that could be used to predict the speed of a pressure feeder in a six roll mill (a three roll mill with pressure feeder and underfeed roll). The surface speed of the pressure feeder rolls (S_p, in m/s) could be estimated from:

$$S_p = \frac{Q_f}{E\,\gamma_{do}} \frac{4\,D_p}{L\left(D_p + W_p\right)^2} \tag{12}$$

where Q_f is the fibre rate (kg/s)
E is the effectiveness
γ_{do} is the compaction (fibre fill) at the exit of the Donnelly chute
D_p is the mean diameter of the pressure feeder rolls (m)
W_p is the pressure feeder work opening.

The surface speed of the pressure feeder rolls can be related back to the pressure feeder roll speed (N_p, in r/min) by:

$$N_p = \frac{60\,S_p}{\pi\,D_p} \tag{13}$$

The fibre rate can be calculated from:

$$Q_f = \frac{C\,F}{360} \tag{14}$$

The effectiveness has been empirically determined as:

$$E = \left(4.63 - 0.88\,\frac{W_{su}}{h^*} - 1.58\,\frac{D'_p}{h^*}\right)\left(\frac{D'_p}{h^*} + \frac{W_{su}}{h^*} - \frac{h_{do}}{h^*}\right)\frac{h_{do}}{h^*} \tag{15}$$

where W_{su} is the underfeed setting (tip to tip distance between underfeed roll and top pressure feeder roll) (m)
h^* is the optimal feed depth for the pressure feeder (kg/m^3)
D'_p is the outside diameter of the pressure feeder roll (m)
h_{do} is the Donnelly chute exit setting (m), the same as K_e in equation (10) except in m instead of mm.

The optimal feed depth for the pressure feeder is a theoretical concept calculated from:

$$h^* = \frac{D_p + W_p}{2} \tag{16}$$

Like the fibre fill at the delivery opening in equation (2), the fibre fill at the exit of the Donnelly chute in equation (12) can best be determined by rearranging the equation and applying it to historical data, similar to that done with equation (11). Rearranging equation (12):

$$\gamma_{do} = \frac{Q_f}{E\ S_p} \frac{4\ D_p}{L\ \left(D_p + W_p\right)^2} \tag{17}$$

The fibre fill at the exit of the Donnelly chute is not really a mill property since the chute is located before and not in the mill. As a result, this parameter is not substantially affected by changes to mill settings and so can be assumed to remain constant irrespective of setting changes.

For the theory in this section to be valid, it is assumed that the mill is operating under chute level control. Wienese (1995) indicated that chute level control is practiced in South Africa, as it is in Australia. Equation (12) is essentially a relationship between fibre rate, mill speed and mill settings. If the chute level is not being controlled (the chute is operated empty), fibre rate and mill speed are not varying in proportion with each other and equation (12) does not apply.

For mills with a pressure feeder and underfeed roll, equations (12) to (15) can be applied directly. For mills with a pressure feeder but no underfeed roll, a change in the effectiveness equation (15) is required. A constant value of effectiveness *E* (1.16 for heavy duty pressure feeders and 1.2 for light duty or toothed pressure feeders) is used.

For mills with no pressure feeder but with an underfeed roll, equations (12) to (15) can be used but there are necessary changes to the rolls in which they apply. Figure 2 shows in green the rolls to which the feeding theory applies. Figure 2(a) shows the six-roll mill geometry and Figure 2(b) the four-roll mill geometry.

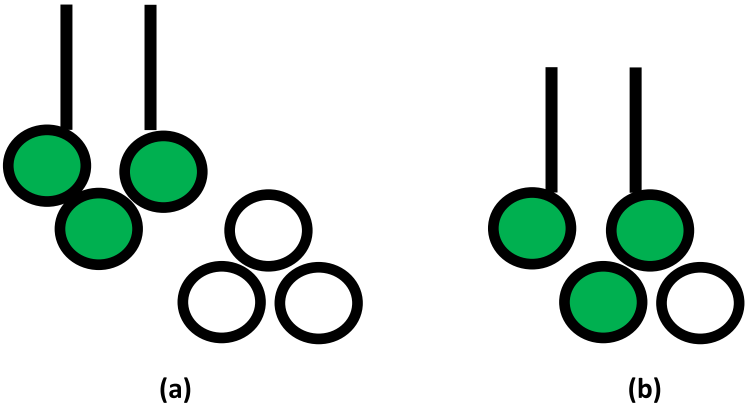

Figure 2. The three feeding rolls of (a) a six-roll mill and (b) a four-roll mill.

Equations (12) to (16) show that, for a given cane fibre rate, the speed of the six-roll mill is affected by the Donnelly chute exit opening, the underfeed opening and the pressure feeder work opening. Using the comparison shown in Figure 2, it can be concluded that, for a given cane fibre rate, the speed of the four-roll mill is affected by the Donnelly chute exit opening, the underfeed opening and the feed work opening.

As reported by Wienese (1995), it is common to set the feed work opening to achieve a feed work opening to the delivery work opening ratio of about two, or to vary the feed work opening as part of a strategy to control reabsorption. While these strategies are effective from a performance point of view, they do have implications for the speed of the mill.

The effect of mill setting strategies on mill speed

A mill for demonstration purposes

To demonstrate the usefulness of the mill feeding theory in the mill setting process, one of Sezela's dewatering mills was examined. Munsamy (2008) provided an almost complete description of this milling unit. To complete the description, further information was required.

Munsamy (2008) reported the use of 38 mm pitch grooving but did not specify the depth. Communications with staff of Sezela mill have indicated that the groove depth was 43 mm. This depth has minimal impact on the feeding calculations but it is noted that the effectiveness equation (15) makes use of the outside diameter of the rolls rather than the mean diameter. The groove depth allows the outside diameter to be calculated.

Munsamy (2008) reported mill settings throughout the season. The medians of these values were used in these calculations: underfeed opening of 216 mm, feed opening of 91 mm, and delivery opening of 41 mm. Munsamy (2008) did not report a Donnelly chute exit opening. Using the guideline reported by Wienese (1995) that the Donnelly chute opening is usually 8-10 times the delivery work opening, a Donnelly chute opening of 369 mm was assumed.

Munsamy (2008) reported top roll lift of 2 mm and delivery roll lift of 10 mm. Adding these lift values to the openings resulted in a feed work opening of 93 mm and a delivery work opening of 53 mm.

Munsamy (2008) does not report the mill speed. Advice from Sezela mill staff is that the minimum allowable speed for the mill is 1 r/min. For the purpose of illustrating the theory in this section, it has been assumed that the speed of the mill was 1 r/min.

For this mill description, equation (17) was used to calculate a fibre fill at the exit of the Donnelly chute of 94 kg/m^3. This value is a little higher than expected, which indicates that the assumed speed of 1 r/min is probably an underestimate. For illustrating the theory in the remainder of this section, the assumed speed is adequate for the purpose.

The effect of the feed to delivery work opening ratio on roll speed

Using the theory and specific mill properties described above, Figure 3 shows the predicted change in roll speed, delivery work opening and feed work opening as the feed to delivery work opening ratio is changed. To calculate the mill settings shown in Figure 3, the fibre fill at the delivery opening was assumed to remain unchanged, simulating constant roll load. Changes in work opening imply changes in either setting or roll lift.

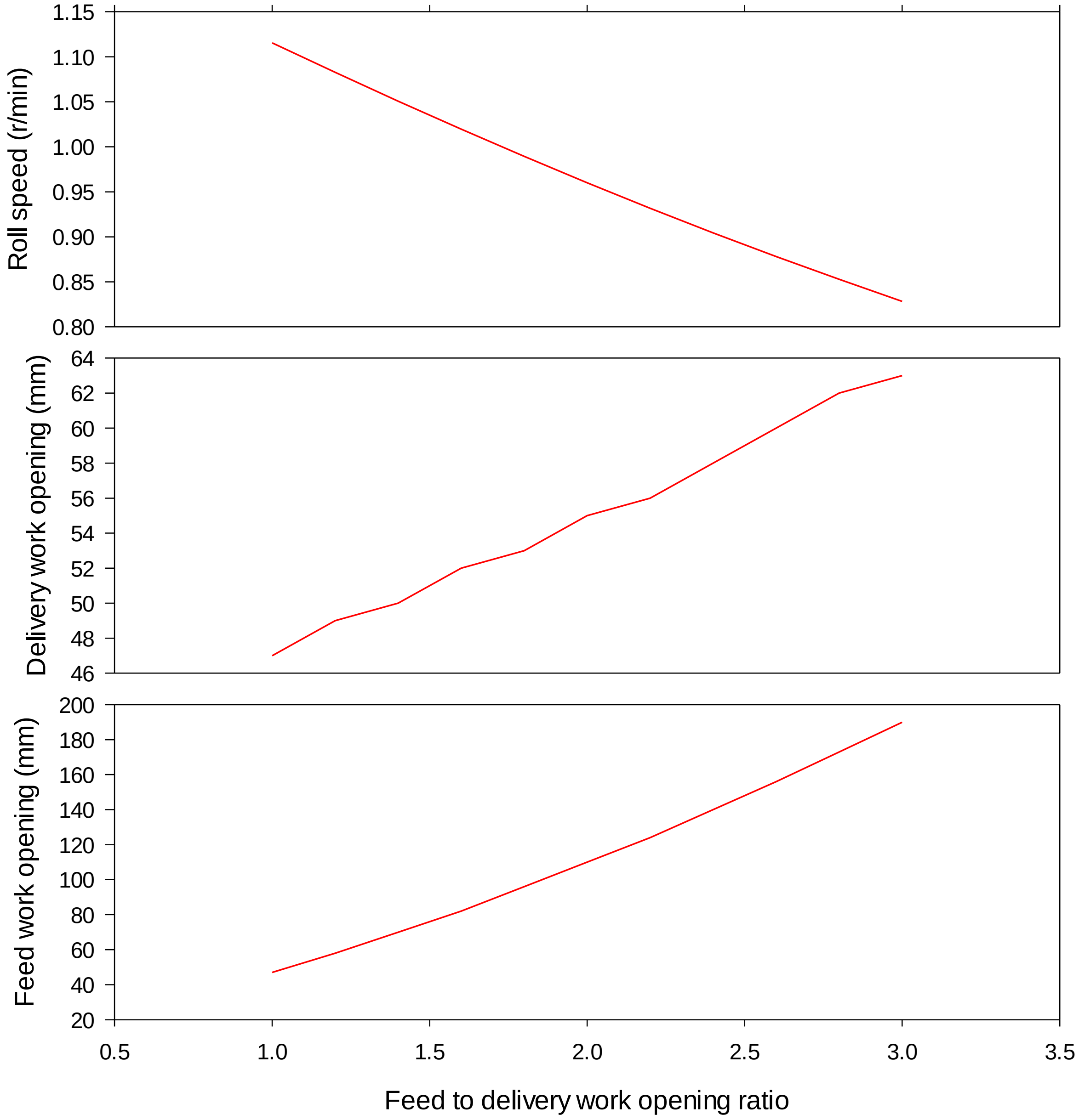

Figure 3. Effect of changing the feed to delivery work opening ratio on roll speed and mill work openings.

Changing the feed to delivery work opening ratio from 1.0 to 3.0 caused the roll speed to reduce from 1.12 to 0.83 r/min and caused the delivery work opening to increase from 47 to 63 mm. Translating this result to a mill setting decision, Wienese (1995) referred to a mill setting approach of reducing the feed to delivery work opening ratio as part of an approach to control reabsorption. Figure 3 shows that, in addition to the desired effect on reabsorption, this strategy has the effect of increasing the mill speed. Changing the mill speed is not a problem provided the settings have been appropriately chosen to ensure roll lift and that the mill drive does not operate at either its minimum or maximum speed. Operating a drive at minimum or maximum speed prevents chute level control functioning correctly, resulting in either an empty or full chute. It is understood that averaging a speed that is 40% through the allowable speed range for a drive is considered good practice in South Africa.

Effect of underfeed opening and Donnelly chute exit opening on roll speed

For a fixed feed work opening of 93 mm, Figure 4 illustrates the effect of different underfeed opening and Donnelly chute exit openings on roll speed.

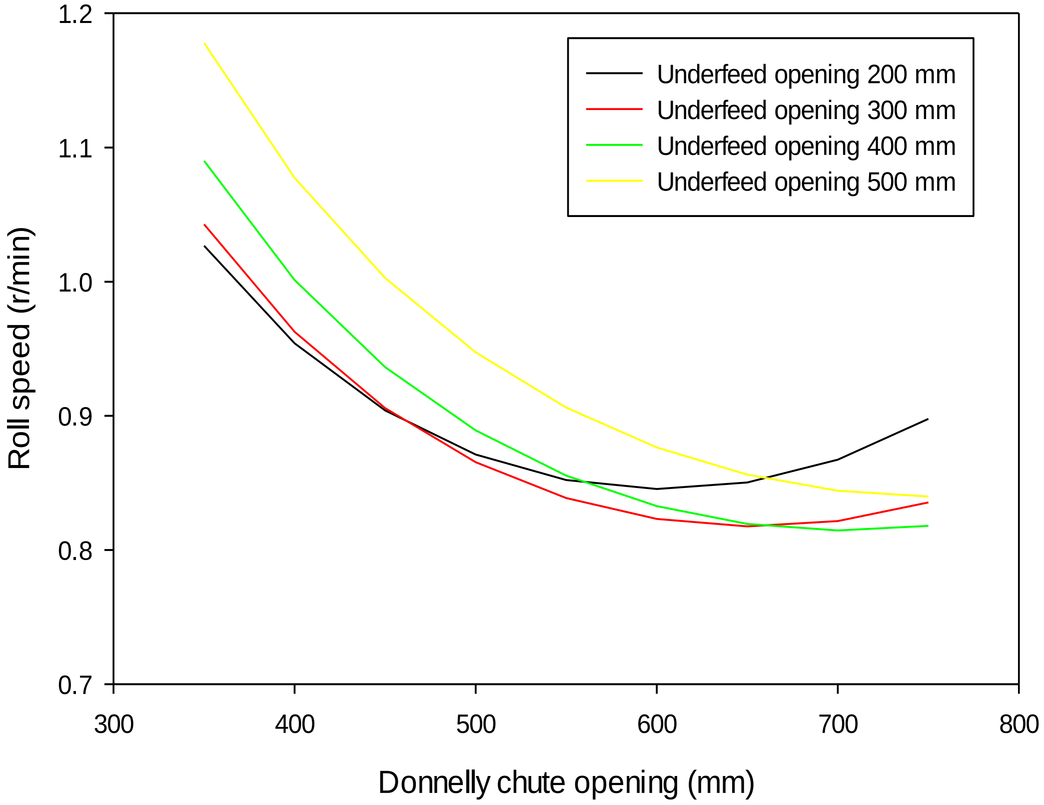

Figure 4. Effect of changing the underfeed and Donnelly exit openings on roll speed.

Probably the first point to note from Figure 4 is that the roll speed of 1.0 r/min corresponding to the underfeed opening of 216 mm and Donnelly chute exit opening of 369 mm is well above the lowest speed shown on the graph, indicating that the selected underfeed opening and Donnelly exit opening do not represent the feeding arrangement of lowest speed.

Looking at each of the curves, it is clear that there is an optimal Donnelly chute exit opening that minimises the roll speed and that the optimal opening increases as the underfeed opening increases. It is also clear that the lowest roll speeds were found with underfeed openings of 300 and 400 mm. No lower roll speed was found with either smaller or larger underfeed openings. This result suggests that there is an optimal underfeed opening also that will minimise roll speed.

Setting changes through the season

It is generally necessary for settings to be adjusted through the season. Firstly, it is common for the mill settings to need some refinement early in the season to optimise mill operation and performance. Secondly, it is generally necessary to adjust for wear of the roll surface. The theory shows that changes to the feed work opening, such as described above to control reabsorption, will change the speed at which the mill operates. Changing the speed will then change the amount of lift that is achieved. Provided the speed and lift do not reach their upper or lower limits, this speed change can be managed. If a limit is reached, the theory described in this paper can be used to make adjustments to move back into a better operating region for speed and lift.

Conclusion

The mill setting procedures adopted in South Africa essentially involve selecting a delivery work opening that will provide a top roll load to enable hydraulically loaded rolls to float. The feed, underfeed and Donnelly chute exit openings are all selected by criteria as multiples of the delivery work opening. Results achieved over many years have clearly shown that this approach works, at least in most cases.

The adopted approach essentially ignores that fact that the selection of mill settings also affects the operating speed of the mill for a particular fibre rate. Under chute level control, there is only one speed that can be used. The mill feeding theory presented in this paper provides a means of understanding the effect of mill settings on roll speed and provides a means of predicting the roll speed for the chosen mill settings.

The mill feeding theory shows that, as the feed work opening reduces, roll speed increases. The theory also shows that there is an optimal underfeed opening and Donnelly chute exit opening that will minimise roll speed and that the current South African guidelines, based on the analysis of one mill examined here, appear to be well away from those optimal values. This conclusion does not necessarily indicate a problem with the current guidelines but does present an opportunity for additional capacity for a mill that is reaching its maximum speed.

Acknowledgements

The author acknowledges the assistance provided by Mr Stanley Munsamy and Mr Johan van Rensburg of Illovo Sugar Limited in providing information about the Sezela mill studied in this paper. Mr Gavin Smith of the Sugar Milling Research Institute is also acknowledged for his assistance in the selection of the topic of this paper and in providing local contacts.

REFERENCES

Jayes WEG (1994). An investigation into performance of a diffuser dewatering mill. *Proc S Afr Sug Technol Ass* 68: 146-150.

Kent GA (2004). Predicting mill speed. *Proc Aust Soc Sug Cane Technol* 26: 10 pp (electronic format).

Munsamy SS (2008). Optimising bagasse dewatering in a cane diffuser at Sezela sugar factory. *Proc S Afr Sug Technol Ass* 81: 154-159.

Russell GE and Murry CR (1968). A method of determining settings for three-roll mills. *Proc Qld Soc Sug Cane Technol* 35: 81-93.

Wienese A (1990). Mill settings and extraction. *Proc S Afr Sug Technol Ass* 64: 154-157.

Wienese A (1995). A milling review. *Proc S Afr Sug Technol Ass* 69: 192-195.