A REVIEW OF THE INFLUENCE OF MILL SIZE ON MILLING CAPACITY

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ABSTRACT

The paper reviews the various factors that influence the capacity of a milling train. The relationship between torque load and power for a range of compactors is discussed for mills of different sizes. The influence of feeding arrangement is reviewed and the effect on capacity of desired extraction performance and shredder configuration is discussed. Estimates are made of the crushing capacity of mills of different size, and the design factors such as shaft, shell and pinion strengths that have to be considered as mills are increased in size, are discussed. Estimates are made of the capital costs of mills of sizes from 1.83 m to 3.05 m and an analysis carried out to determine the capital cost per unit of crushing capacity. This analysis establishes that there tends to be a minimum cost for mills of around 2,500 mm length but that factors such as increased compactors and minimum operation costs can favor larger units.

INTRODUCTION

The question “What is the capacity of a milling train?” has similarities with the question “What is the length of a piece of string?” in that there are a multitude of answers. In the case of a milling train, however, the factors that influence the answer are able to be more readily defined and their effect calculated.

The physical factors influencing milling capacity include the size of mill rollers, strength of the rollers, type of feeding device, operating speed, power available and the fiber characteristics and preparation of the cane being handled. The level of extraction performance required also implies a capacity limit.

The demand for milling units of increased capacity is quite strong as many millers strive to achieve economies of scale in their crushing operations. This paper reviews the principal factors which influence milling capacity, with particular emphasis on the effect of mill size, and discusses the aspects of mill design that have to be considered as mill size increases up to in excess of three metres roller length.
The principal factor in mill design is the level of compaction that is required to be achieved in the delivery/squeeze. The desire for the highest squeeze possible is tempered by considerations of power requirements and increased reabsorption at higher fiber compactions. Russell and Murry\textsuperscript{12}, based on studies with the University of Queensland two roll mill, established the relationship between top roll load and filling ratio as

\[ R = \text{PPR} \cdot D \cdot (C_f - 0.1) \]

where,
- \( R \) = Top Roll Load per unit length (MN/m)
- \( D \) = Roll diameter (m)
- \( C_f \) = Filling ratio at delivery = Fibre compaction
- \( \text{PPR} \) = Proportionality factor dependent on the fineness of preparation and the position of the mill in the train (MPa)

This relationship can be used to estimate the roll loads for a range of milling compactions. Figure 1 illustrates this relationship for a 2.13 m mill using PPR factors typical of those for the Bandaberg area.

The relationship between torque on a pair of rolls and top roll load was established by Murry\textsuperscript{9} as

\[ G = \text{NRD} \]

where,
- \( N \) = Torque Load No. \( G \) = Torque (MN m)
- \( D \) = Diameter (m) \( R \) = Top Roll Load (MN)

Munro\textsuperscript{7} established from experimental data an estimate for the torque load number for a pair of rolls as

\[ N = \text{PP} \cdot (\frac{C_f}{D})^{0.5} \cdot \left( \frac{W_0}{D} \right)^{0.5} \]

where,
- \( \text{PP} \) = Proportionality factor dependent on fineness and mill position
- \( W_0 \) = Work opening of rolls (m)
Figure 1 shows the relationship between top roll load and milling torque (the torque absorbed in the compaction of cane in the three roll mill) for values of PP typical of those in the Bundaberg area. The power absorbed in milling can be derived from the milling torque by making allowances for frictional losses in the mill scrapers and bearings, drive efficiencies, the effect of feeding devices and the operational speed. Figure 1 shows the estimated milling powers for a mill fitted with a heavy duty pressure feeder and operating at a peripheral speed of 300 mm/sec.

**Figure 1.** Relationship between top roll load, filling ratio and torque – 2.13 m mill.

**THE EFFECT OF MILL SIZE ON OPERATING LOADS, TORQUES AND POWERS**

Based on relationships similar to those illustrated in Figure 1, it is possible to develop the relationships between load, torque and power shown in Figure 2 for mills from 2.1 m to 3.0 m length. Figure 2 has been developed, based on the assumption of No. 1 and No. 5 filling ratios of 0.45 and 0.62 respectively, and at a surface speed of 300 mm/sec.

Figure 2 illustrates the significant increase in torque and load requirements as mills increase in size. For example, torque requirements for a 2.8 m No. 1 mill are 1.94 times those for a 2.13 m mill. Power requirements at
constant peripheral roller speed are only approx. 33% higher. It must be emphasized that powers referred to are absorbed powers and sufficient allowance has to be made for operational consideration when estimating installed powers.

### CAPACITY OF AN INDIVIDUAL MILL

The crushing capacity of a mill of a given length is influenced by such factors as the fineness of preparation, the height of the feed chute and the roller length. The results obtained are given in Fig. 2.

**FIGURE 2.** Relationship between roll load, torques and powers for mills of from 1.83 to 3.05 m length.
a high duty feeder. In the above expression, the capacity of mills has been
whilst a heavy duty feeder increases capacity by a further 27.5% above that of
the normal capacity of a mill with unmetered roll stand, approx. 40%,
whether duty feeder. A 27% increase implies that a 2.12 m roll for a 2.8 m mill, a high duty
heavier duty pressure load 1.1 mill (c. 2.8 m in England) is seen to have a capacity

The table below has been prepared to demonstrate the relative capacities of mills

Secondly to achieve optimum performance:

To the mill mouth and retard the central affection to the pressure feeder simply
when today heavy and high duty feeders provide greater pressure capacity
the high work gradient and increased speed of the mill - typically 1:1.75 -
design is influenced by excess juice pressure (provided online recirculation of juice
while a mill pressure load 1.1 mill). 

The heavy duty pressure feeder developed by CSR (Severn) is well as

From this it is clear that:

Rearranging the equation to express the pressure in terms of the pressure

and mill position

\[
\text{Pressure} = \frac{P}{d}
\]

where

\[
\left[ \frac{d^2}{d^2} - 1 \right] = \frac{P}{d}
\]

and D = diameter.

The relationship between pressure and bore force (bore density or

and the hydraulic

Horsehold and function in an investigation of recovery feed through mechanical

and the diameter.

Where WD is the weight of dry

and the speed of the press is \( \frac{100}{t} \) m/s. Where WD is the weight of dry

established that the optimum feed density (to provide the elevated volumes in the

and the hydraulic press (which presents the volume at the receiving plane). Minor

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FIGURE 3. Relationship between mill length and crushing capacity for No. 1 and No. 4 mills for heavy duty (HD), light duty (LD) and No. 3 roll mill with underfeed.
FACTORY ENGINEERING

considered on the basis of a peripheral speed of 300 mm/sec. Australian practice is to use this as a nominal maximum, although this speed is exceeded in many milling countries. Bullock investigated the influence of milling speed on coefficient of friction and found the coefficient to fall with increasing speed, thus reducing potential throughput. Hugot used this as a basis of suggesting a formula for reduction in relative capacity with increased speed. Hugot suggests a formula for maximum speed which varies from 300 mm/sec for a 2.13 m mill to 360 mm/sec speed for a 2.8 m mill. In the capacity reduction formula suggested by Hugot, a 20% increase in speed from 300 to 360 mm/sec is accompanied by an 8% increase in the "slip" factor, which limits the effective increase to approx. 12%. In the absence of more detailed factory scale investigations, the estimates suggested by Hugot appear to present a suitable upper speed limit.

CAPACITY OF A MILLING TRAIN

In determining the capacity of a milling train, there are several considerations:

a) Physical capacity of mills to handle the material
b) Ability of the train to achieve the desired extraction
c) Compatibility with shredder

a) Physical capacity of mills

Figure 3 has illustrated the capacity of individual mills. The physical capacity of mills in the train needs to be "matched" by reducing operating peripheral speed through the train as in Australian practice or by reducing settings. It also illustrates the influence that different types of feeder can have on a milling train's potential capacity. One point to note is that while a heavy duty fed mill may have a certain capacity, a following mill of the same size with only an enclosed chute and underfeed roll as feeder may not be able to accommodate that rate, thus reducing the potential throughput of the train.

b) Ability of the train to achieve the desired extraction

The extraction of a milling train is influenced by such factors as the number of mills, speed of operation, degree of preparation and quantity of maceration. Russell has demonstrated the influence of maceration and number of mills and produced the data illustrated in Figure 4 for fairly coarse preparation. The fall-off in extraction with increasing speed has also been demonstrated by Munro using a 0.66 m diameter two roll experimental mill where a reduction in Brix extraction of a No. 1 mill of 5.5 units in doubling the operating speed from 200 to 400 mm/sec was found.
FIGURE 4. Relationship between number of mills in a train and extraction for a range of maceration levels.
c) Compatibility with shredder

The influence of various operating parameters on shredder performance has been discussed by Cullen. Throughput of a milling train approximates a square law relationship with length whilst throughput of a shredder is linear with length. Operating capacities with shredders rarely exceed 250 t/hr/m width. As the size of mills increases therefore, they become progressively "mismatched" for throughput with shredders of similar length. This is illustrated in Figure 3.

From the above discussion it can be seen that whilst mills may possess the physical capacity to crush the quantity of cane required, the demands of an "acceptable" extraction limit operating speeds, require additional mills in the train or demand finer preparation. The ultimate decision on milling capacity thus depends on economic investment decisions.

MECHANICAL CONSIDERATIONS

Shaft and shell considerations

As mills become longer and greater forces are required to achieve desired compactions, significant increases in the mass of rolls occur. Table 1 illustrates the increased masses that have to be accommodated by lifting equipment. An analysis of the stresses in the shell based on the review by Crawford shows that the axial stresses in the shell due to loading, which are the stresses that lead to shell cracking, reduce by approx. 18% by going from 2.13 m to 3.05 m roll length (based on diameter of half length).

<table>
<thead>
<tr>
<th>Mill length (m)</th>
<th>2.13</th>
<th>2.5</th>
<th>2.75</th>
<th>3.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass shaft</td>
<td>12.0</td>
<td>16.0</td>
<td>27.5</td>
<td>32.5</td>
</tr>
<tr>
<td>Mass roller</td>
<td>7.0</td>
<td>12.5</td>
<td>14.5</td>
<td>21.5</td>
</tr>
<tr>
<td>Total</td>
<td>19.0</td>
<td>28.5</td>
<td>42.0</td>
<td>54.0</td>
</tr>
</tbody>
</table>

Pinion and gearing design

Historically mills have been driven by a single tailbar to the top roller with mill mounted pinions to transmit the torque to both bottom rollers. This
arrangement has proven satisfactory to date, even though many of the small mills are now working at throughput and compactions much higher than their initial design requirements.

In more recent times, with the manufacture of larger mills (up to 2,800 mm roll length), users have required these new installations to accommodate higher compactions than those achieved in the smaller mills. The results of this trend is that the traditional drive arrangement becomes inadequate in the area of both the torsional shear stress in the shaft square and capacity of mill mounted pinions to transmit the torque. These considerations have lead to all mills installed to date which are 2,750 mm or more long being driven by multiple tailbars. This design could also follow through to the smaller size mills if it was a requirement to design the installation to work at compaction at the top of the range (or in excess) of those now being achieved. In practice, confirmation that the limit of the traditional drive arrangement has been reached in some installations is given by the frequency of mill pinion failures (Clarke2 and Tyzack3) and the occurrence of cracking in the drive squares of top rollers.

Mill gearing designs for the larger mill final motion gearings are becoming extremely large and require the use of significantly improved materials than have been used in the past. Recent Australian practice has been to use forged rims of 4330 steel with increased pressure angles to 25 degrees.

Relative costs of milling units

An estimate has been made of the cost of milling units of sizes ranging from 1.83 to 3.05 m in length. These costs are based on a No. 1 mill design for a surface speed of 300 mm/sec and for a filling ratio of 0.45. Costs have included the turbine, high speed and low speed gearing and the mill fitted with a heavy duty pressure feeder and underfeed roll. It has been assumed that mills larger than nominally 2.5 m in length are driven by multiple tailbars.

Figure 5 has been prepared to illustrate the relative cost of mills. This information, combined with the capacity information for No. 1 Heavy Duty Pressure feeder mills in Figure 3, has enabled the relative cost of a mill per ton of cane per hour to be determined. It can be seen that the capital cost of a mill per ton of cane crushed falls as mills increase in size up to around 2.5 m in length, but that the cost rises as mill size increases above this because of the demands for increased performance and compactions required by installers of these units and the greater costs of manufacture of the increased masses of the rolls and gearing.
CONCLUSIONS

From the discussions of the various factors that influence mill throughput it can be appreciated that careful attention to many factors must be given if the design capacity is to be achieved at the desired level of extraction.

Whilst physical size of the milling unit is the prime determinant of capacity, feeding arrangements and powers installed also play a very significant part. The outcome of discussions on the factors that affect milling capacity have highlighted the need for the matching of shredder capacity to milling capacity and have suggested that economies of scale do not, of necessity, automatically follow from larger mills. It must be remembered, however, that the larger designs of mills have been built to accommodate higher levels of squeeze to assist in maximizing extraction and to minimize maintenance and other operating costs by reduction of the number of units.

It is hoped that the factors discussed in this review will enable those contemplating new milling train installations to weigh up the various alternative available to them to come up with a well-balanced configuration.

REFERENCE

7. Munro, B.M. (1964a). An investigation into crushing bagasse and the influence of imbibition on extraction, University of Queensland, Ph.D. Thesis. 152.


16. UNE ETUDE SUR L'INFLUENCE DE LA GRANDEUR DES MOULINS SUR LA CAPACITE DU TRAIN DE MOULIN

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RESUME

Ce travail presente les facteurs qui influence la capacite d'un train de moulins. La relation entre le couple et la puissance pour differentes compressions, est discutee pour des moulins de differentes tailles. L'influence de l'alimentation est discutee. On presente aussi les effets de l'extraction desiree sur la capacite. L'importance du shredder est mentionnee. On evalue la capacite des moulins de differentes tailles. On discute aussi le dimensionnement des axes et pignons, quand la taille des moulins est augmentee. Le cout des moulins de 1.83 m a 3.05 m est evalue ainsi que le cout par unite de broyage. Il se pourrait qu'il y ait un cout minimal pour des moulins de 2.50 m de long. Des compressions plus fortes et les couts d'operations peuvent toutefois modifier ce resultat et favoriser des moulins plus grands.
UNA REVISION DE LA INFLUENCIA DEL TAMANO DEL MOLINO EN LA CAPACIDAD DE MOLIDA

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RESUMEN

El papel revisa los distintos factores que influencian la capacidad del tren de molida. La relación entre el torque y la fuerza para un rango de compactación es discutida para molinos de diferentes tamaños. La influencia de los arreglos de alimentación es revisada. El efecto en capacidad a una deseada extracción y la configuración de una desfibradora son discutidos. Estimados son hechos en la capacidad de molida en molinos de diferentes tamaños y factores de diseño como son la fortaleza de la maza y el piñon que tiene que ser considerados cuando los molinos aumentan de tamaño, son discutidos. Estimados son hechos del costo de molinos de tamaño desde 1.83 m hasta 3.05 m y se hace un análisis para determinar el costo por unidad de capacidad de molida. Este análisis establece que parece haber un costo mínimo para molinos de alrededor de 2500 mm de largo pero factores como el incremento de compactación y costo de operación mínimo pueden favorecer unidades más grandes.