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OPERATION OF SUGAR MILLS WITH INDIVIDUAL VARIABLE SPEED DRIVES

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Abstract

Operation of sugar mills with individual variable speed drives corresponds to propulsion of each roll of the sugar mill independently by electro-hydraulic variable speed or electro-mechanical variable frequency drives. This paper presents the results of the tests carried out in Santa Isabel sugar mill in Brazil, when each four roll mill of four mill tandems was driven by four hydraulic motors of the same size; two of them mounted on the both sides of the top roll and one of them on each inferior roll. It was found that the best way of operating the mill from a mechanical and operational point of view is to keep the torque distribution between the rolls (pressure in the hydraulic systems) at 50, 25, and 25 %. This arrangement has the advantage of using motors of the same size, providing the optimum application of the torque to the mill. Operation of the mill with higher cane roll speed in relation to the top roll speed and lower baggase roll speed, gives better feeding of the cane to the mill and lower reabsorbtion. Because of the variable speed of the drives and different speeds of the rolls, the mills could be operated with almost constant torques on each roll. The numerical operational results of the tandem as capacity, extraction and power consumption are very impressive.

Keywords: hydraulic, drive, independent, mill, torque, speed

Introduction

Individual direct drives refer to the separate propulsion of each mill roll by a drive placed directly on the shaft of each roll. The first mill driven with this method was reported in Cuba (Abon, 1986) when the results of torque distribution on the rolls, depending on the relative speeds of the inferior rolls in respect to the top roll, were presented. This installation was the result of the collaboration of Ministry of Sugar (MINAZ) and the Hägglunds company starting with the introduction of the first high torque hydraulic motors in Cuba in 1976. At that time, the drive was formed by Hägglunds hydraulic motors and the one stage planetary reducers that gave rise to a Hydrodrive of the Mannesmann Rexroth company, where high speed hydraulic motors and three stage planetary reducers from the companies belonging to this consortium were combined. A similar work was presented 10 years later in Mexico (Muñoz and Lewinski, 1996). In the 1980s Hägglunds developed higher torque hydraulic motors, allowing driving mill rolls individually, and eliminating the need for planetary reducers. The German company Flender, well known manufacturer of gear reducers, introduced into the market a Hydrex-Planurex system, combining a high torque hydraulic motor of their own manufacture and a one-stage planetary reducer. These high torque hydraulic motors with and without planetary reducers were very well received in the marketplace due to their great advantages:

1. Partial or full elimination of conventional gears and crown gears.
2. Elimination of the tail bar.
3. Reduced space required.
4. Reduction of loads on roll shafts.
5. No foundations required.
6. Maximum torque in all the speed range; i.e., from zero to maximum speed.
7. Reversible movement.
8. Continuous speed variation separately in each roller.
9. Protection against overloading and almost immediate interruption of mill operation.
10. Automation of the milling process possible.
11. Measuring the torque of each of the rollers.
12. Ease of maintenance.
13. Greatly reduced size and weight.
14. Power savings (high efficiency in transmission, use of electric power, load reduction in journal bearings).
15. Increased extraction (optimisation of the extraction process).

The main advantage is the independent variable speed of each roll, which allows for the optimisation of the mill's operation from a mechanical (torque distribution) and operational point of view (extraction, pol in bagasse, moisture in bagasse) (Lewinski, 2005).

Another way of applying individual drives to sugarcane mills has been the use of planetary reducers engaged directly to or through the cardan shaft with AC electric and variable frequency motors, a well known solution in the sugarcane industry for driving tables, drivers and cane conveyors.

Although direct mill operation experiences have been present for over 20 years, there is no published information yet as to how to operate these mills (torque distribution, speed distribution, mill adjustments, etc.). This work intends to provide some answers to such questions.

Description of the testing methodology

To carry out the tests, a mill tandem driven by high torque electro-hydraulic drives (without planetary reducers) was selected. Each mill is driven by four high torque hydraulic motors of the same size, directly placed on the mill's rolls (two motors over the top roll and one over each lower roll) (Figure1).

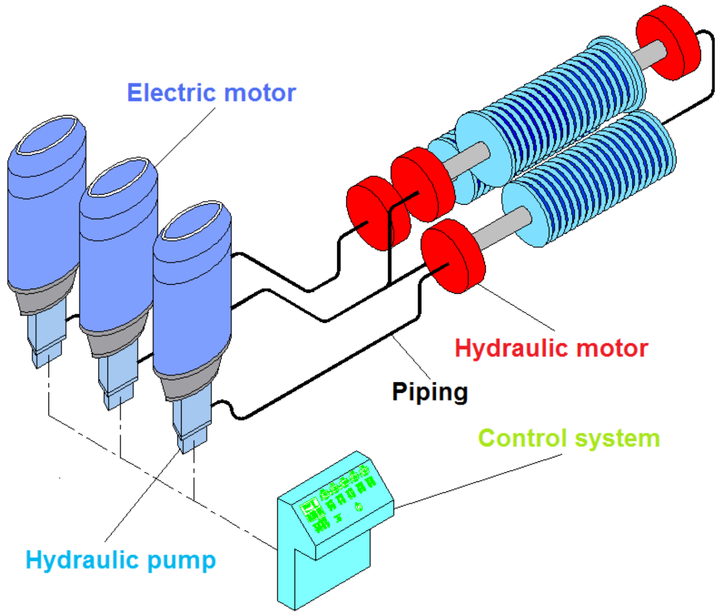

Figure 1. Individual direct electro hydraulic drive.

Each hydraulic motor is moved by an electric motor which drives a variable flow hydraulic pump, allowing for the operation of the motors at the speed range of 0 - n max (n max – maximum rotational speed of the rollers). The flow is transmitted to the motors through piping, which allows for great flexibility of positioning for the power units (electric motor, plus pump, plus accessories) in relation to the hydraulic motors. The tandem is integrated by four mills and located in the Santa Isabel sugar mill in Brazil (Figure 2.

Figure 2. Milling tandem driven by hydraulic motors in Santa Isabel sugar mill.

Mill 1 is 7 foot long and the remaining mills are 6.5 feet each. The tandem is automated (Figure 3), the feed of mill 1 is controlled to maintain the same level of chute at the determined range and the remaining mills automatically vary their speed to maintain their level of chute within the predetermined ranges. Measurements included the torque on each mill shaft (continuous pressure measurement for each hydraulic system), and the shafts speed (sensors placed directly on the hydraulic motors).

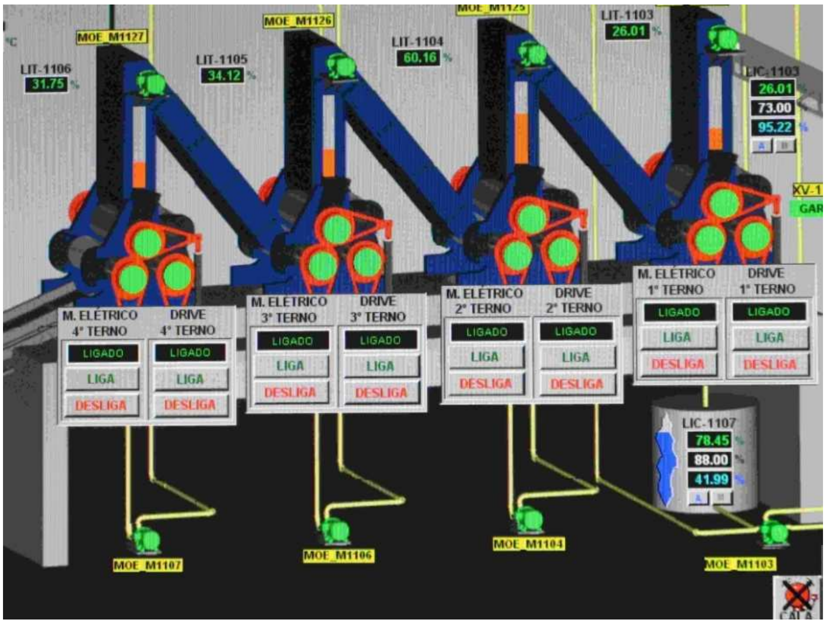

Figure 3. Display of the control system in the Santa Isabel sugar factory.

The desired results are:

1. Torque distribution.
2. Speed distribution (ratio of rpm of the inferior rolls in relation to the top roll).
3. Power distribution on the mill rolls.
4. Total power consumed by each mill.
5. Total power of tandem.

The results will be related to laboratory results: TCH (milling capacity in metric tons cane per hour), corrected reduced extraction, pol and moisture in bagasse of the whole tandem, as well as the extraction of mill 1.

In 2008, three different scenarios were analysed for the mill settings defined by the consultant of the mill to operate mills at a speed of 6.6 rpm and the calculated capacity of 584 TCH. The actual operating speed of mill 1 was adjusted to 6.0 rpm, to theoretically grind 550 TCH.

Scenario 1
Distribution of torque 50, 25 and 25% − the best one from the standpoint of optimal capacity performance of hydraulic motors (equal pressure on all hydraulic systems of the mill). For this purpose, the RPM ratios were experimentally determined).

Scenario 2
Equal peripheral speeds for all mill rolls – a case considered by several researchers at the mill as optimal for mill operation.

Scenario 3
Equal rotational speed for all mill rolls – as is the case of mills with conventional transmissions equipped with crown gears.

In 2009 the mill was operated according to scenario 1. Mill settings were the same as those of 2008 for theoretically milling 584 TCH at a speed of 6.6 rpm. The hydraulic pressure at the heads of the mills was reduced by 7-15%. Two measurements were made in June for an approximate period of one hour, looking for the stable operation period of the mill (2009-1A and 2009-1B) and a measurement for a period of over five hours in October the same year (2009-2), when the operation of the mill was more stable.

Results

Figures 4 and 5 show examples of the behavior of the mill in each scenario (year 2008) where:

TR − top roll
CR – cane roll
BR – bagasse roll
Friction − angular speed ratio between the inferior rolls and the top roll
FCR − angular speed ratio between the cane roll and the top roll
FBR − angular speed ratio between the bagasse roll and the top roll.

Scenario 1 has proven to be the most appropriate, taking into account the optimal use of the drives and the distribution of speed. All hydraulic motors are the same size and they all work with the same pressure, which allows their optimal use in terms of maximum operating pressure and efficiency. The cane roll always rotates at the higher rotational speed, which helps to achieve the best feeding and the bagasse roll, on rotating at the lower speed, reduces the reabsorption phenomenon. In all the scenarios above, the torque on the top roll is constant, notwithstanding any mill speed variations and speed ratios and it is 50% of the total torque produced. The power consumed at the top roll is 50% of the total power consumed by the mill, regardless of the scenario. It was recommended to operate the mills under scenario 1 (torque distribution 50, 25 and 25%) and in 2009 all the mills operated under such conditions.

Figure 6 shows the measurements made in 2009 in the month of June, when tandem work was not stable (continuous recording time of approx. one hour) and Figure 7 shows the results of all the mills recorded in the month of October when tandem operation was quite stable (continuous recording time of approx. 5 hours). Table 1 presents the numerical average results of all measurements; Table 2 shows the total power consumed by the whole tandem in all the tests and Table 3 shows the laboratory results during the whole tandem tests.

Operating results are impressive considering the number of mills and their size (milling about 600 TCH). The extraction in mill 1 was reported as 84% and the maximum extraction of the whole tandem was 97%. As compared with 2008, the torques generated in the mills were significantly lower, resulting in less total power consumption with similar or even better operating results. The total power consumed by the tandem was approximately 2600 kW which, taking the number of mills into account, the cane fibre (approx. 12%) and the capacity per hour (approx. 600 TCH) gives a mean specific power of mill of 9 kW/ton of fibre/hour on the mill. The total value of the power consumed by the whole tandem is an even more impressive value.

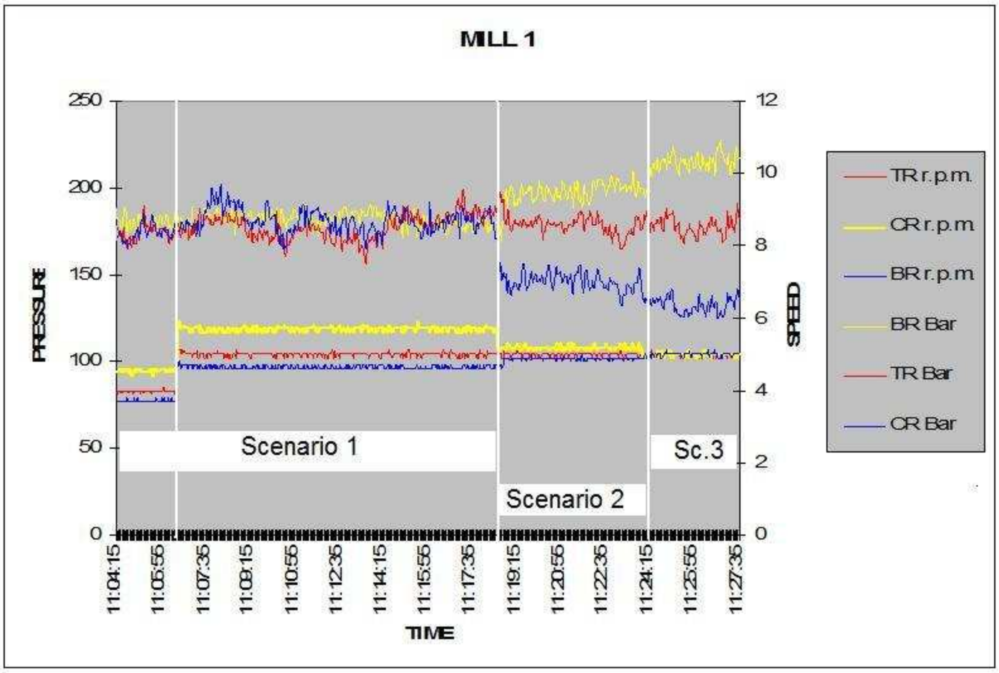

Figure 4a. Mill 1 – Pressure:speed ratio (direct measurement).

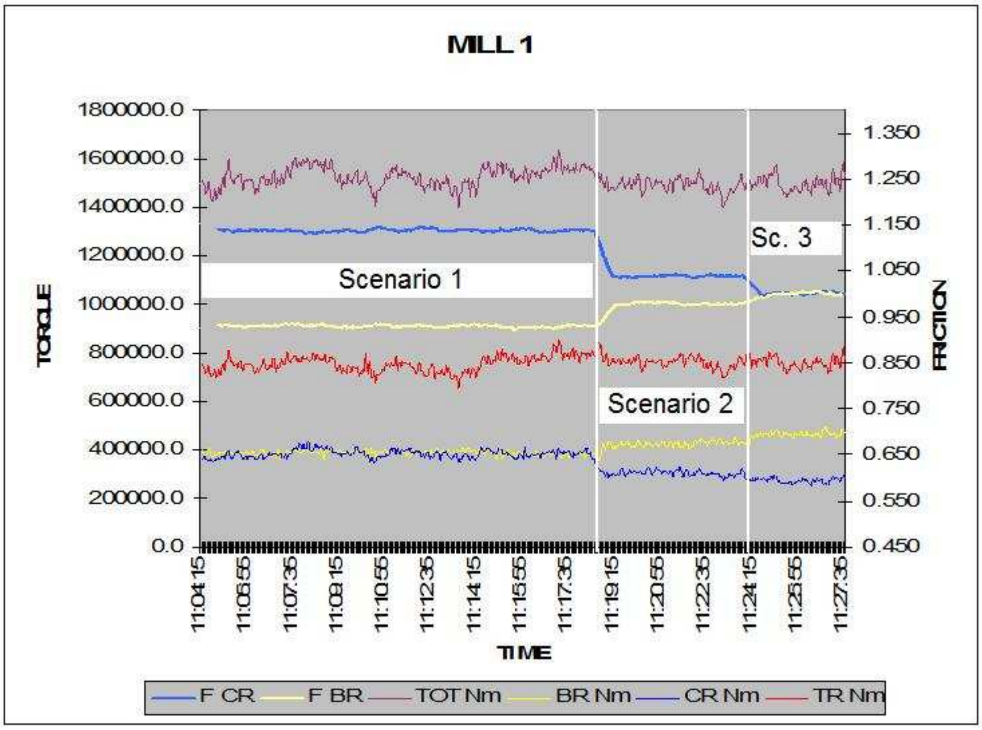

Figure 4b. Friction:torque ratio.

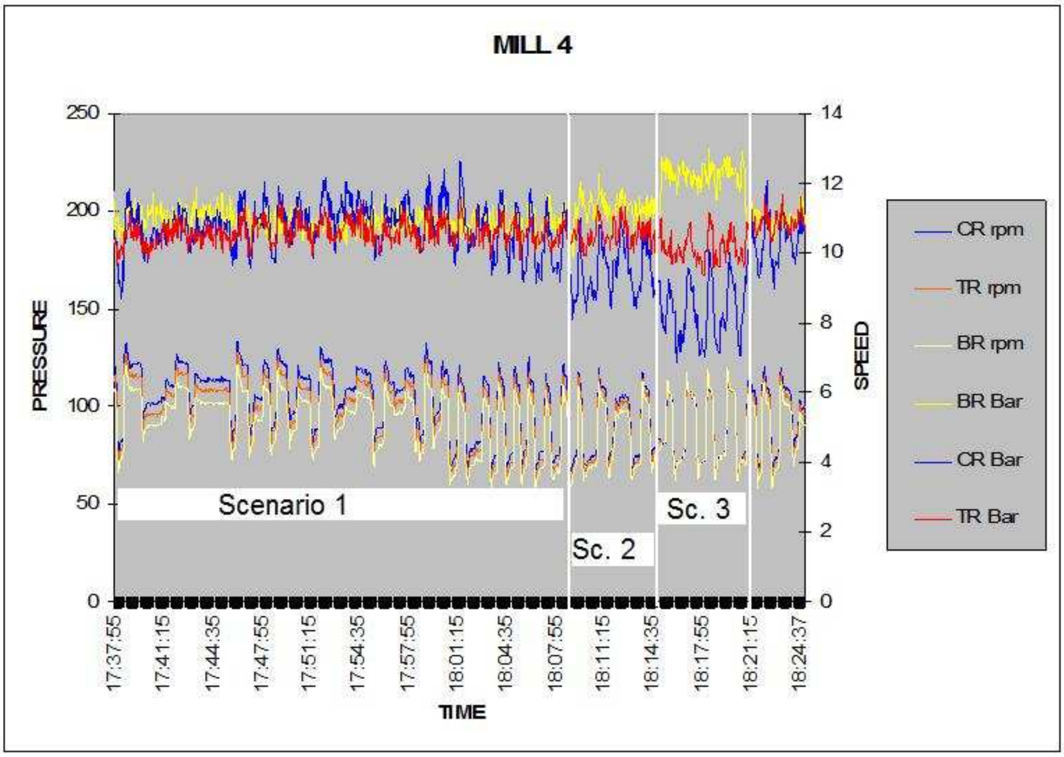

Figure 5a. Mill 4 – Pressure:speed ratio.

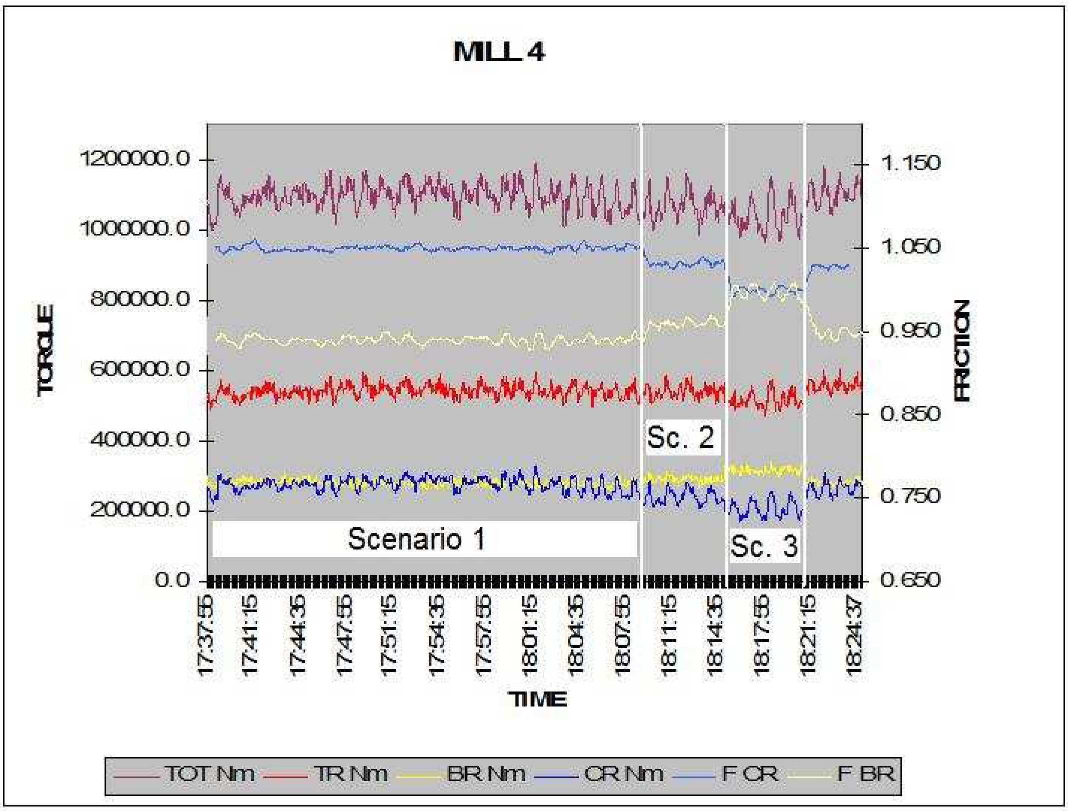

Figure 5b. Mill 4 – Friction:torque ratio.

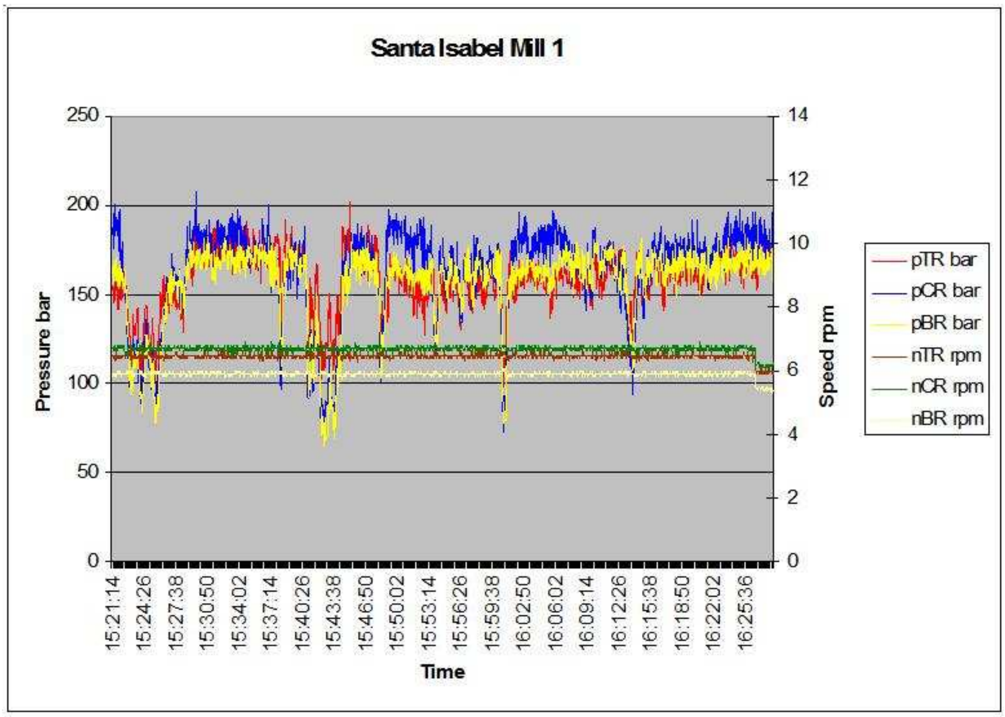

Figure 6a. Mill 1 – Speed:pressure ratio.

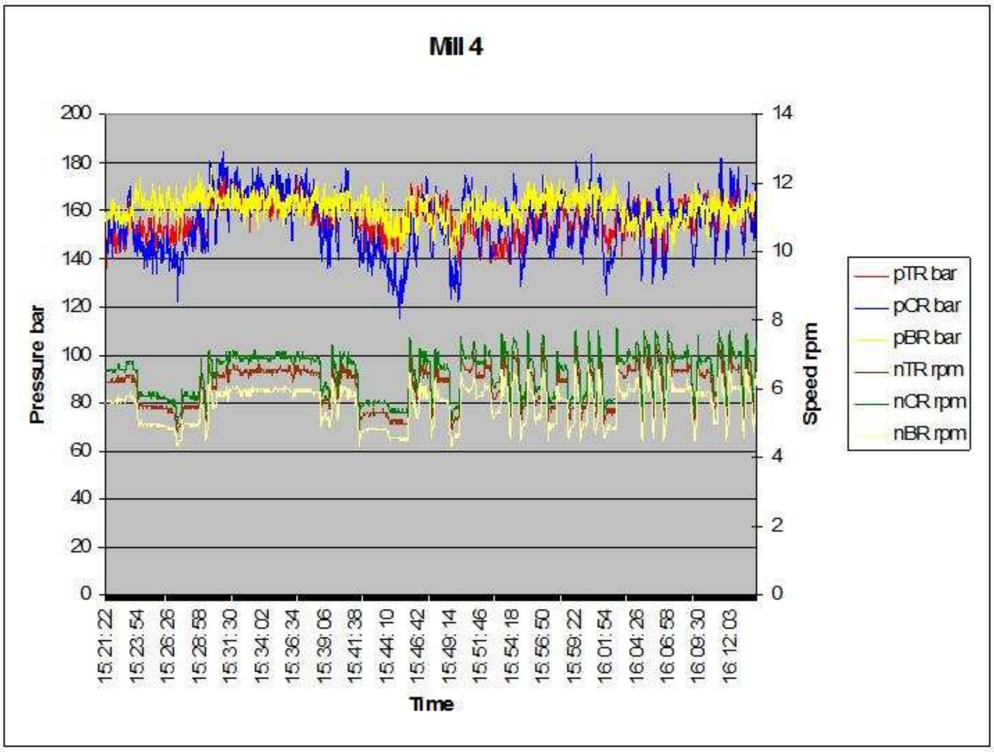

Figure 6b. Mill 4 – Pressure:speed ratio.

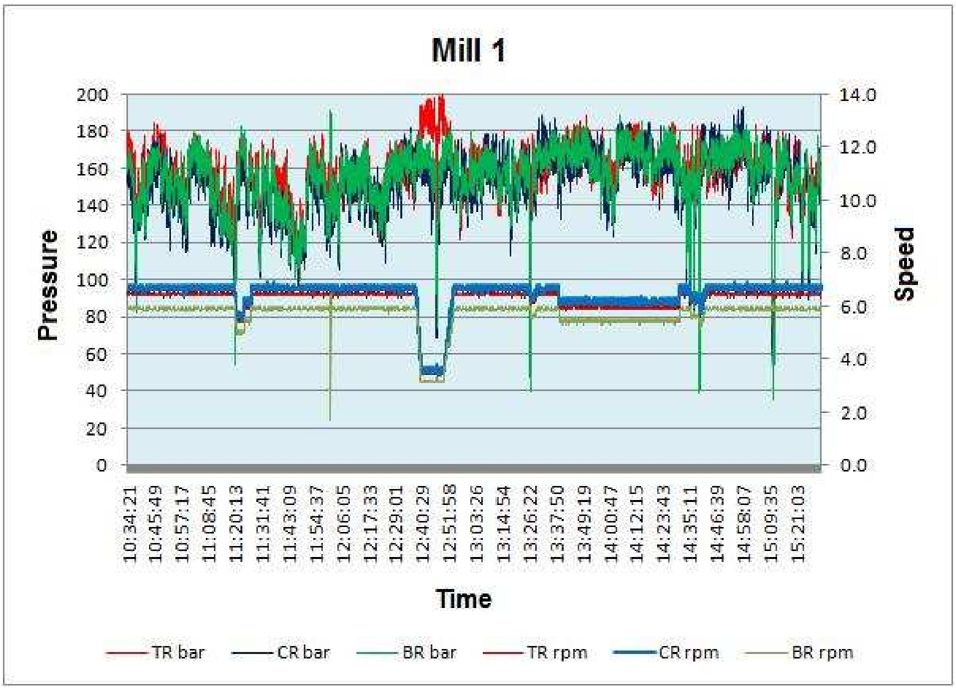

Figure 7a. Mill 1 – Pressure:speed ratio.

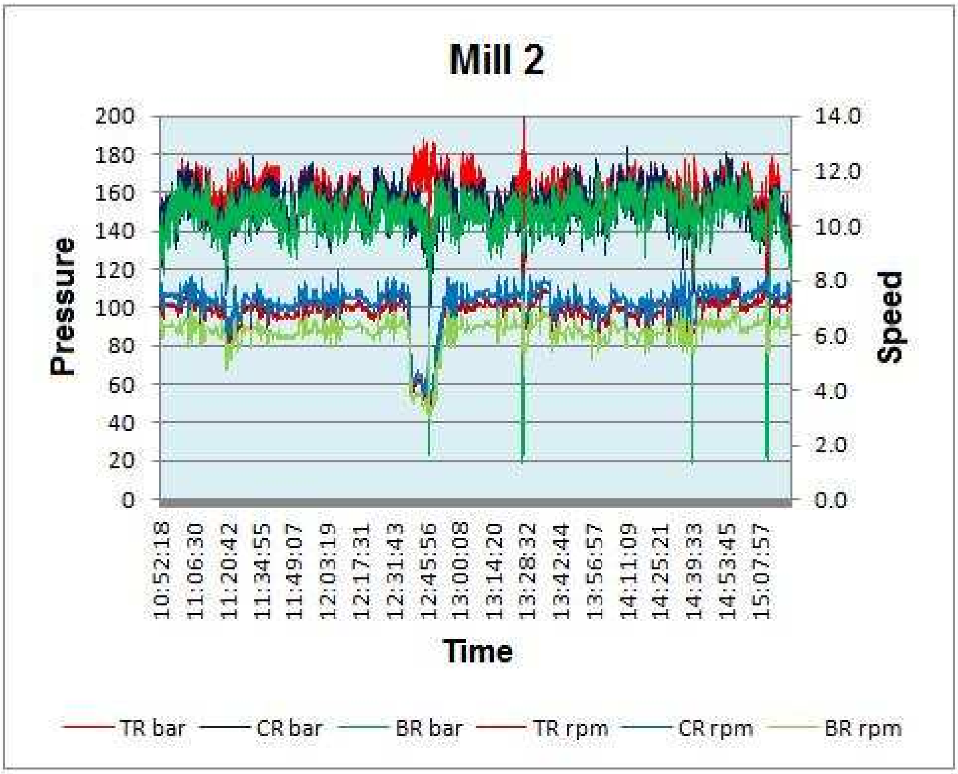

Figure 7b. Mill 2 – Pressure:speed ratio.

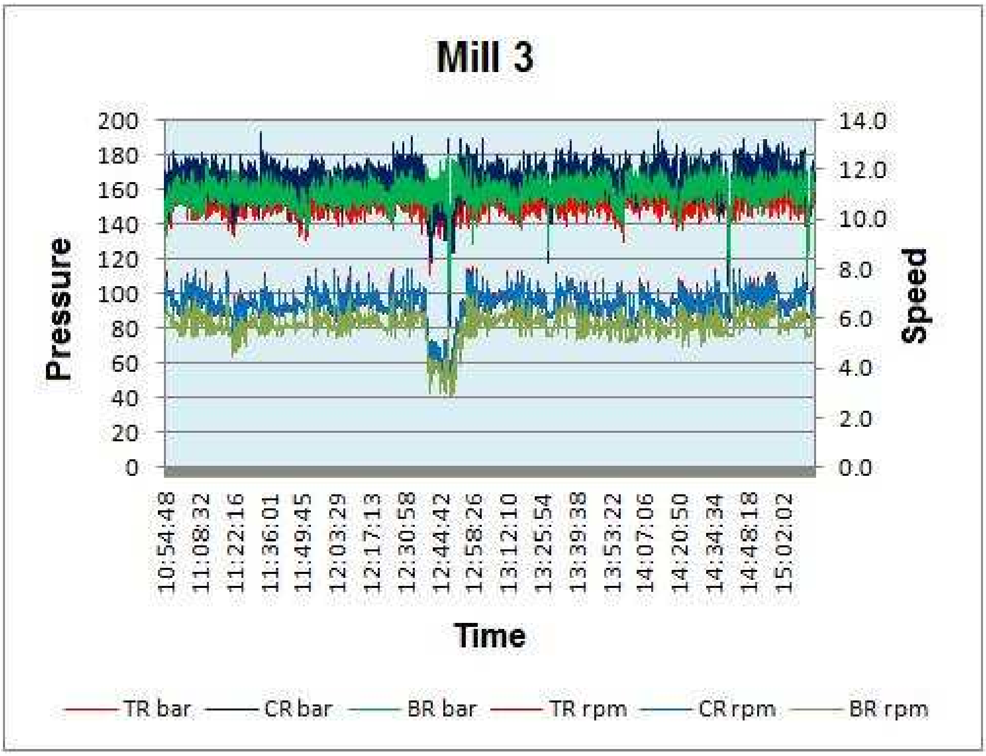

Figure 7c. Mill 3 – Pressure:speed ratio.

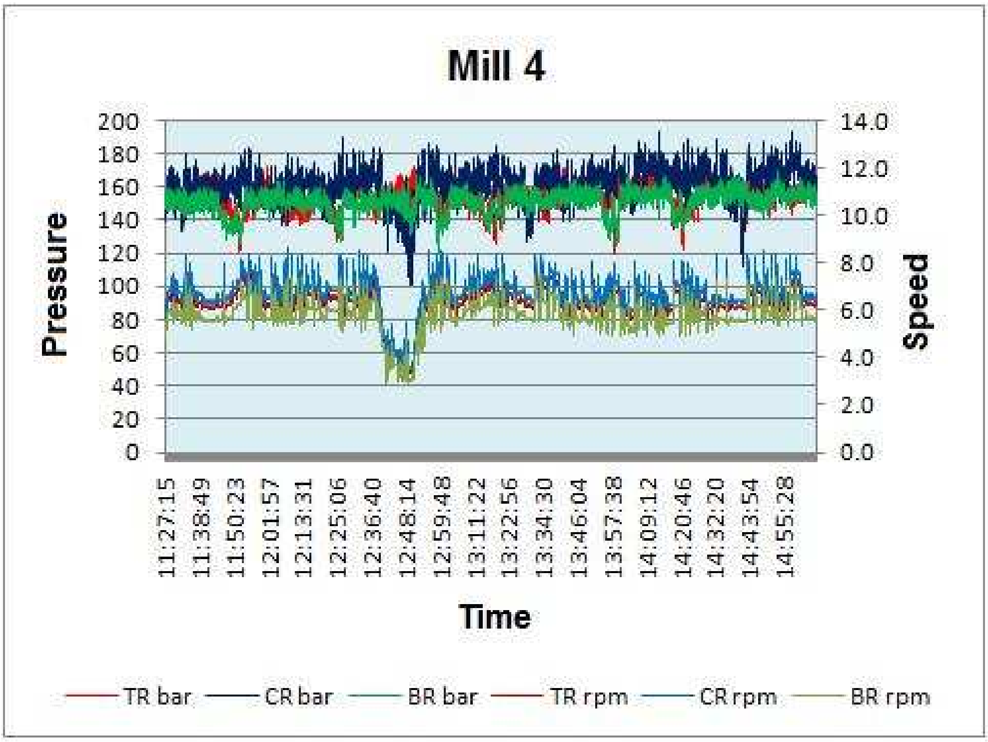

Figure 7d. Mill 4 – Pressure:speed ratio.

Table I - Average numerical results of all measurements.

MILL	TESTS	PRESSURE			SPEED			TORQUE				POWER			
		TR bar	CR bar	BR bar	TR RPM	FCR	FBR	Total Nm	TR %	CR %	BR %	Total kW	TR %	CR %	BR %
	2008 SC. 3	195	121	203	5.0	1.00	1.00	1493417	51	21	28	781	51	21	28
	2008 SC. 2	186	197	188	5.0	1.04	0.98	1529224	55	19	26	800	55	19	26
	2008 SC. 1	187	180	184	5.0	1.15	0.95	1577250	51	24	25	821	50	27	23
1	2008 SC. 1	188	184	172	6.0	1.15	0.95	1564145	51	25	24	1006	50	28	22
	2009-1A	156	165	166	6.5	1.04	0.92	1391719	49	26	26	910	49	27	24
	2009-1B	158	162	156	6.5	1.03	0.91	1370462	50	25	25	894	51	27	22
	2009-2	158	151	155	6.2	1.03	0.91	1309833	51	24	25	841	52	25	23
	2008 SC. 3	192	162	201	5.7	1	1	1067541	52	21	27	630	52	22	27
	2008 SC. 2	190	189	193	5.5	1.06	98	1090592	50	25	25	635	49	26	25
	2008 SC. 1	198	185	189	5.6	1.03	0.97	1101944	51	24	25	643	51	25	24
2	2008 SC. 1	195	194	190	6.7	1.03	0.97	1107455	50	25	25	777	50	26	24
	2009-1A	156	158	169	6.6	1.05	0.90	922561	49	25	26	617	49	26	24
	2009-1B	162	156	162	6.7	1.05	0.89	927151	50	24	25	627	51	27	22
	2009-2	158	150	148	6.9	1.05	0.89	860216	52	24	24	608	52	26	22
	2008 SC. 3	188	171	212	5.1	1.01	0.98	1084312	49	22	28	584	50	23	27
	2008 SC. 2	192	186	197	5.0	1.03	0.95	1097073	50	24	26	572	50	25	25
	2008 SC. 1	194	199	195	5.2	1.03	0.95	1120708	50	25	25	614	50	26	24
3	2008 SC. 1	198	202	192	6.0	1.03	0.95	1135501	50	26	24	715	50	27	23
	2009-1A	156	162	169	6.2	0.99	0.82	896636	47	26	27	541	49	27	24
	2009-1B	153	161	155	6.3	0.98	0.80	895730	49	26	25	543	52	27	21
	2009-2	152	165	158	6.5	1.00	0.88	879676	49	26	25	583	50	27	23
	2008 SC. 3	185	159	210	4.9	1.02	0.98	1052240	50	21	29	546	50	22	28
	2008 SC. 2	188	175	198	4.8	1.04	0.95	1069083	50	23	27	539	50	24	25
	2008 SC. 1	190	192	195	5.0	1.05	0.94	1095205	50	25	25	570	50	26	24
4	2008 SC. 1	189	194	196	5.8	1.05	0.94	1098780	49	25	26	669	49	27	24
	2009-1A	157	149	164	6.1	1.05	0.92	904055	50	24	26	558	51	25	24
	2009-1B	156	155	161	6.1	1.06	0.91	903403	50	25	26	558	50	26	24
	2009-2	154	161	151	6.4	1.05	0.91	870705	50	26	24	575	50	28	22

Table 2. Total power consumption in the whole tandem.

TESTS	MILL 1 RPM	POWER TANDEM KW
2008 SC. 3	5.0	2541
2008 SC. 2	5.0	2546
2008 SC. 1	5.0	2648
2008 SC. 1	6.0	3167
2009-1A	6.5	2626
2009-1B	6.5	2622
2009-2	6.3	2607

Table 3. Laboratory results.

TESTS	CAPACITY TCH	Extraction %	Pol in bagasse %	Moisture in bagasse %	Fibre in cane %
2008	572	95.65	2.7	48.5	12.42
2009 - 1	578	96.13	2.24	47.9	11.6
2009 - 2	602	95.94	2.4	48.3	12.09

Conclusions

With individual drives the mill can be operated with different speed distributions between the rollers, thus making it possible to operate the mill with the same peripheral speed of all rollers or with the same rpm of all the rollers, as in conventional mills, or changing the speed ratio of inferior rolls in respect to the top roll, in search of the higher cane roll speed (better feeding) and lower speed of the bagasse roll (less reabsorption). This last option, for conventional settings of the mills, may be achieved by adjusting the roller speeds to maintain a similar pressure in all the hydraulic motors, which will result in the same torque applied to the shaft ends of all the rollers. For this option all the hydraulic drives may be operated at their optimum capacity, maximising the mill torque, thus avoiding an overload of the hydraulic systems and generating the same stress at the ends of roller shafts.

At Santa Isabel sugar factory, the use of the scenario of the same pressure in all hydraulic motors helped achieve better operating results as compared to the previous year. The four mill tandem was milling 600 TCH with a maximum extraction of 97% and with an extraction at mill 1 of up to 84%. These results were achieved with less total power consumption than the previous year.

Future work should focus on finding the optimal values of speed distributions for torque distribution 50, 25 and 25% by optimising the settings of the mills to these new work conditions.

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