Mill Drives: a reliability comparison study **July/2019**

Inserted in a competitive environment where sugarcane growing areas are declining as well as sugar prices are also lowering, leading to cost reduction requirements, are some of the major challenges in the current sugar industry.
This is accompanied by rising energy and labor costs, competition between sugarmills for cane suppliers, increased productivity and a much higher plant availability.
As seen in most mills in the Philippines as well as in other traditional sugar producing countries like Australia and Brazil where mills are around 100 years old, investment on replacement and upgrade of mill drives is currently needed. Considered a critical investment within the sugarcane industry the gearbox choice requires knowledge in both ends, research and real examples to back up the theory.

With this background the present study proposes an analysis on the available drive options for convetional sugar mills taking into account its sensitiveness and focusing on the reliability of each option aiming the highest plant availability and consequently reliability.

New drive solutions and applications are surpassing the mechanical limits of conventional drive systems serving to utilize the principle of economies of scale. By elimination of various components of the drive train, the maintenance activities and spare parts inventories are reduced. Examples of this reality are seen in the windpower generation and some cogeneration processes where new technologies are been applied eliminating the speed reducer or multiplier.

The principle idea behind it is to reduce the number of components and diversity of parts. Especially those components that are most likely to present failures. This results in more reliable machines and finally in a more realiable plant.

According to Ross (“A Modern Probability Course with applications", page 110), the reliability of a machine is equal to the product of the individual reliability of each of its parts susceptible to failure. This basic concept is defined by the below formula:

Image 1

Rg = Global reliability of the machine
Ri = Individual reliability of each part of the machine
n = Number of machine parts susceptible to failure
T = Working time

$$Rg = ((Ri)^n)^T$$

Example:

A machine with 22 parts and the individual reliability of each part is 99.8% in the 5-years period, we have:

$$Rg = ((0.998)^{22})^5$$

Global reliability is Rg = 0.8 = **80%**

Using this definition and applying it to speed reduction machines, the susceptible parts that can present failure are all the dinamic elements like gears, pinions and roller bearings.

If only one of these parts or any contact point between them fails, the whole machine stops. That is the reason why global or integral reliability is the product of each part's individual reliability. The more elements susceptible to failures, the more reliability decreases and consequently the chance of failures increases.

Transporting this concept to drive options available for sugarmills, 3 possibilities were chosen to be analysed: central helical/parallel gearbox, central foot mounted planetary and shaft mounted planetary drives.
As this study was based in Brazil, it was considered an American industry set up which is a 3 roller mill, consisting on 1 pressure feeder only on a total of 4 rollers per mill.
It is excluded from this analysis the coupling failure possibility.

When using a central helical/parallel torque division gearbox there will be 6 gears contact points (Image 2) plus 3 pinion gears (one on each of the 3 remaining rollers) to transfer the torque to the remaining 3 rollers. And 12 roller bearings, one on each side of the shafts (Image 3). Meaning that in this drive option a total of 21 points of contact or failure possibilities per mill is observed (6 + 3 + 12 = 21) as shown in the images below.

Image 2

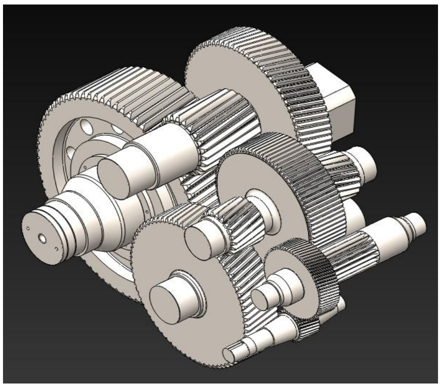


Image 3

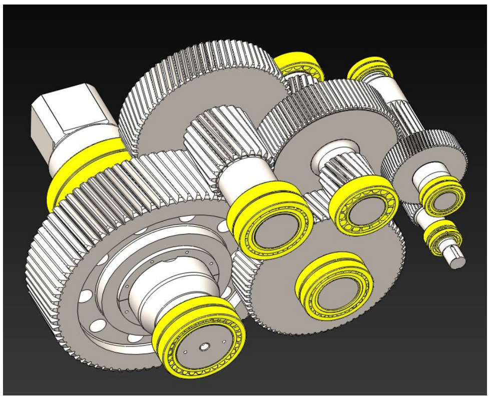
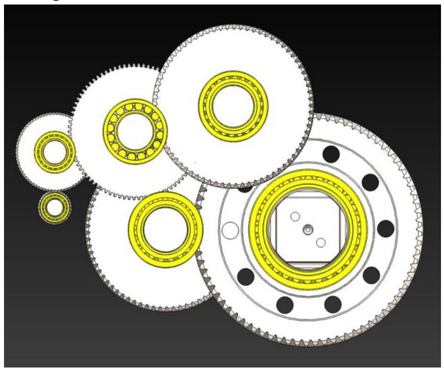


Image 4



If a central planetary drive is used, it will be 22 gears contact points (as seen on Images 5 to 8) plus 3 pinion gears (one on each of the 3 remaining rollers) and 23 roller bearings (Images 9 and 10), totalizing 48 failure possibilities per mill (22 + 3 + 23 = 48).

Image 5

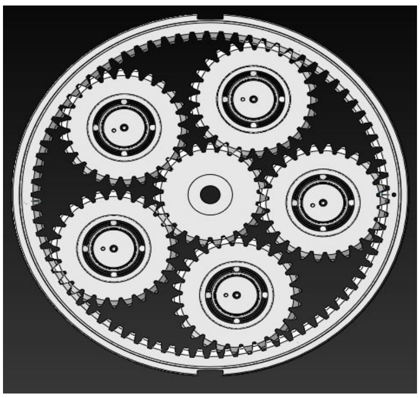


Image 6

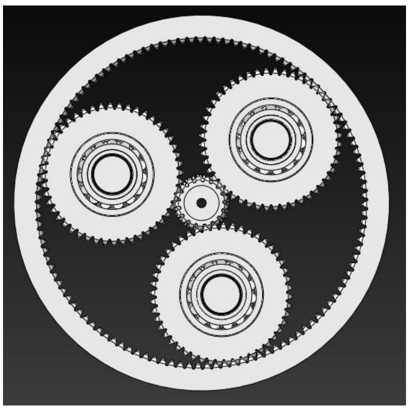


Image 7

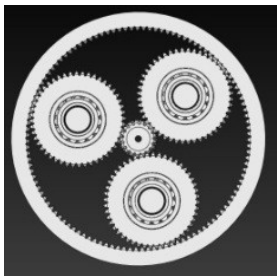


Image 8

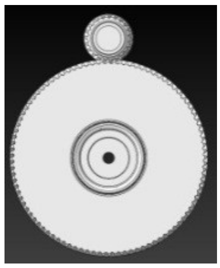


Image 9

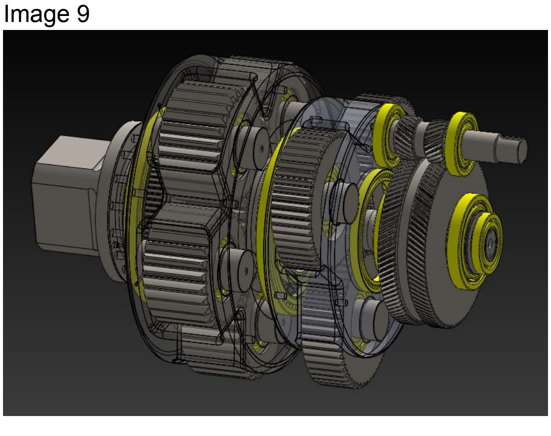
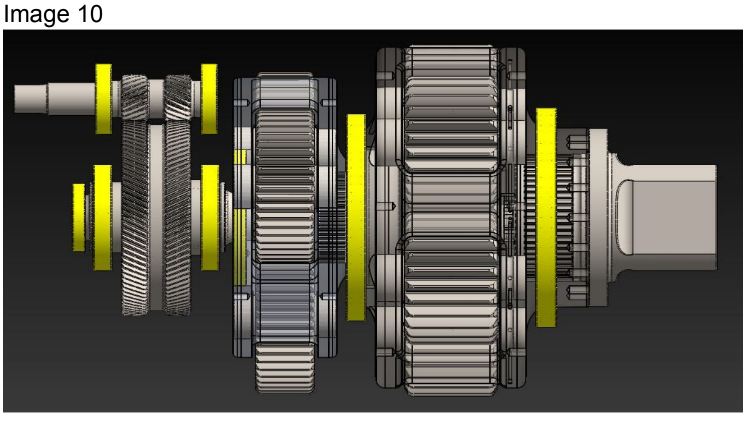


Image 10



When a planetary shaft mounted option is chosen, 110 gears contact points are needed per mill considering only 5 planetaries (as mentioned, our study evalutes a 4 roller mill instead of a 6 roller one), so 22 gears contact points per drive (as seen on Images 5 to 8 above) times 5 planetary units per mill equals to 110 contact points. No pinion gears are needed but 115 roller bearings are placed within those 5 planetary drives (as shown on Images 9 and 10). So a total of 225 failure possibilities per mill are observed.
Organizing these numbers in a table, a clear comparison between them can be seen below.

Table 1

	Helical/ Parallel torque division (Torqmax)*	Planetary foot mounted (central drive)*	Planetary shaft mounted (5 drives per mill)**
gears contact points (gearbox)	6	22	110
pinion gears	3	3	0
roller bearings	12	23	115
total points of contact	21	48	225
failure probability (gears+bearings)	0,00025	0,00025	0,00025
failure probability (pinion gears)	0,00025	0,00025	0
acceptable failure probability (%)	10		
critical failure probability (%)	20		

* considering a 3 roller mill + 1 pressure feeder: 3 pinion gears are needed for central drives (planetary and helical/parallel).
** considering a 3 roller mill + 1 pressure feeder: 5 planetaries shaft mounted are needed (no pinion gears are needed).

Placing the total points of contact or the number of machine parts susceptible to failure in the formula shown on Image 1 and assuming the same failure probability (0,00025 or 0,025%) to each part for a period up to 15 years of working time or 15 crushing seasons, our study revealed the probability of failure of each drive option within its working time.

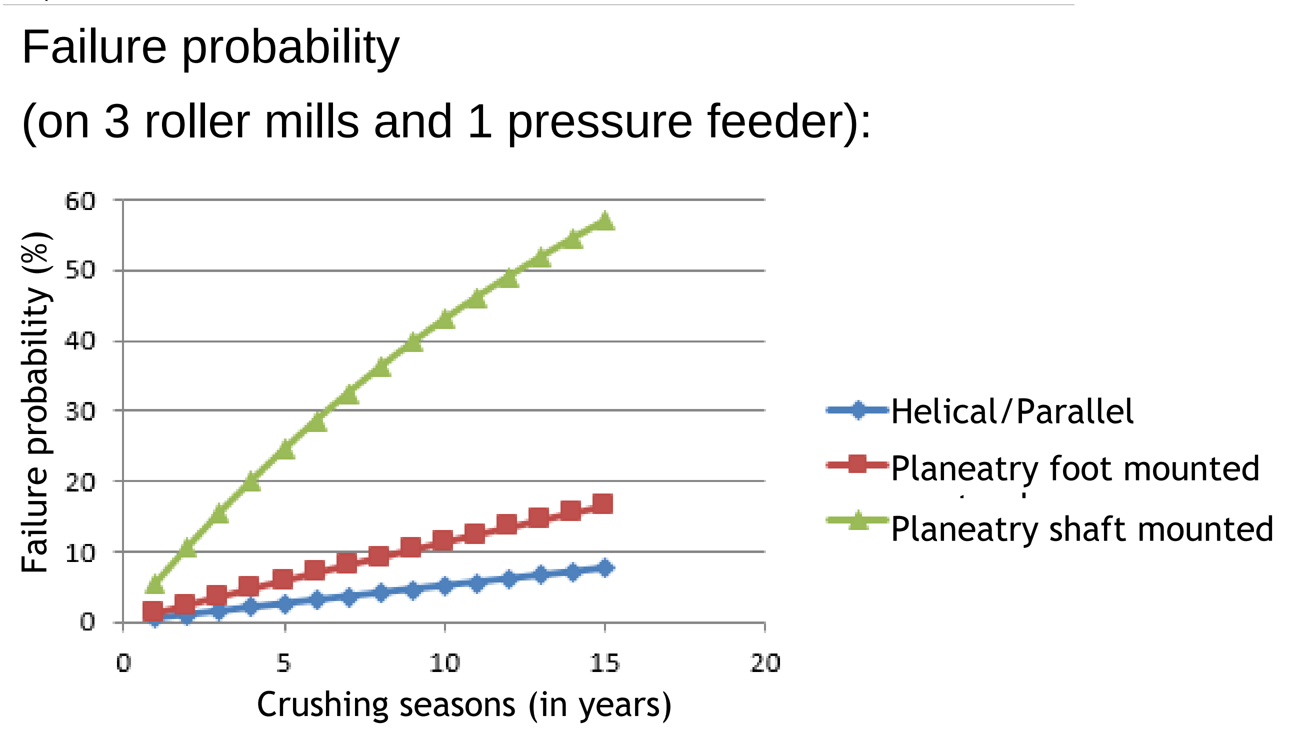
As seen in the Table below (Table 2), on the left hand side it is shown the period of working time in years, considering a 240 days crushing season, while the columns enroll the probability of failure for each machine type after every crushing season.
In accordance to our experience, a machine is considered reliable if it presents up to 10% possibility of failure (graphed in green color), from 10% to 20% failure possibility it has an acceptable reliability (marked in yellow color). When a machine reaches 20% possibility of failure, it can no longer be considered reliable and it is advisable to proceed with its replacement (red colored).

Table 2

Crushing seasons (in years): 240 days per season (8 months)	Helical/Parallel	Planetary foot mounted	Planetary shaft mounted
1	0,52369	1,19298	5,47039
2	1,04464	2,37172	10,64152
3	1,56286	3,53640	15,52978
4	2,07836	4,68719	20,15062
5	2,59117	5,82425	24,51869
6	3,10129	6,94775	28,64781
7	3,60873	8,05784	32,55105
8	4,11353	9,15469	36,24077
9	4,61567	10,23845	39,72865
10	5,11519	11,30929	43,02572
11	5,61209	12,36735	46,14244
12	6,10639	13,41278	49,08865
13	6,59810	14,44575	51,87370
14	7,08724	15,46639	54,50640
15	7,57381	16,47486	56,99507

Since 1950 as a gearbox maintenance and repair shop in Brazil and since 1976 as a gearbox manufacturer to the Brazilian and overseas markets our experience proves this theory.
Planetary drives have required maintenance in much shorter time periods than parallel ones, as in the case of parallel or helical units that have long periods of time between maintenances and replacements. This reality can also be seen in the graphic that follows:

Graphic 1



On the Y axis of the graphic the failure probability of the analyzed drive option is seen and on the X axis the years of operation, showing once again the decrease of reliability of each machine for a according to the years of operation. The blue line indicates the failure probability of a helical/parallel drive from the first crushing season until the 15^{th}, the red line shows the same probability for a planetary foot mounted option and the green one refers to planetary shaft mounted.

Essentially what has been theoretically proved and experienced so far reverts back to one of the most important concepts in any industry or business, how should a machine reliability be measured and valued to justify its initial investment?

Overall the summarized benefits to support further discussions on the investment level of a machine with lesser parts susceptible to failure are:

– Higher reliability

– Higher reliability leads to higher plant productivity due to higher availability (as the machine is expected to be available and ready for operation)

– Minimized risk of downtime by eliminating components, couplings, bearings and gears of the machine itself and the whole system required for its operation

– Reduced maintenance resulted from higher reliability and fewer components within the machine and its system

– Longer life cycle of the machine meaning that a replacement will be needed only after a longer period of time.

Clarification note: this study didn't consider hydraulic motors as a possible drive option to conventional mills due to its replacement in the American sugarcane industry.