# INVESTIGATION OF A MILL DRIVE FAILURE

By

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**KEYWORDS: Turbine, Mill, Drive, Vibration, Alignment.**

## Abstract

THE NUMBER one mill drive at Bingera Mill is a conventional, Australian six roll mill fitted with a heavy duty pressure feeder. The mill drive comprises a single stage steam turbine, a high speed gearbox and a low speed gearbox driving the top roll and bottom pressure feed roll through tail bars. The number one mill drive suffered three broken turbine rotor shafts, a failed coupling between the turbine and high speed gearbox and broken teeth on the input shaft of the high speed gearbox during the 2005 crushing season. The paper describes work done to investigate and correct the problem with the mill drive while making best efforts to continue operation of the factory.

## Introduction

The first mill at Bundaberg Sugar's Bingera factory is a conventional, Australian six roll mill fitted with a heavy duty pressure feeder.

The mill drive comprises a single stage steam turbine, a high speed gearbox and a low speed gearbox driving the top roll and bottom pressure feed roll through tail bars. The underfeed roll is chain driven from the bottom pressure feed roll.

The top pressure feed roll and the side rolls are driven by pinions from the bottom pressure feed roll and top roll respectively.

Cracking of the low speed gear bed was discovered during the 2004 crushing season. The low speed gear bed of the mill was removed, refurbished and re–installed during the 2005 maintenance season.

## The failures

The turbine rotor shaft of Bingera's first mill broke on 11 July 2005, approximately two weeks into the 2005 crushing season. Four days after fitting a replacement turbine rotor, the number one mill turbine tripped.

On restart, the replacement turbine shaft broke and another replacement rotor was fitted. The shaft of this rotor broke nine days later.

Following the three broken turbine rotor shafts, teeth snapped off the input shaft of the high speed gearbox on 24 July 2005. A decision was then taken to bypass number one mill, something not done at Bingera in at least the previous 40 years.

**Bypassing the first mill**

The first mill of a tandem plays a critical role. Loss of the first mill of a tandem would typically reduce overall extraction by about two units due to the combined effects of fewer maceration washings and the adverse effect on the fineness of the bagasse and the opening of juice cells.

Further, the first mill is typically an integral part of the sampling system that forms the basis of the cane payment scheme in Australia.

Consequently, bypassing the first mill of a tandem is not straightforward and is attempted only when there is essentially no alternative.

By bypassing the first mill, the Bingera factory managed to continue operating despite the failure of number one mill's drive. Essentially, the second mill in the tandem became the first mill. Bypassing the number one mill was a significant undertaking.

Number one mill was bypassed by taking the front out of the Donnelly chute and installing a slide down onto 1A intermediate carrier. This effectively isolated the number one mill, allowing its drive to be worked on while crushing continued.

A complication was the cush stream that normally dropped into 1B intermediate carrier from the rotary cush screen. This problem was solved by diverting the cush stream to the side onto an old, demountable sugar conveyor that fed the cush stream back into the discharge bagasse of the second mill.

The juice pumps at number three mill were stopped and the juice allowed to overflow to the mixed juice collection pit via an existing drain.

Only a minor change to the control system was necessary. The speed of the prepared cane elevator was made a manual input used to set crushing rate and the prepared cane elevator was interlocked with 1A intermediate carrier rather than number one mill.

The speed of the cane carrier continued to be run at a fixed ratio of the speed of the prepared cane elevator and the speed of number two mill continued to be varied in response to the height of feed in its Donnelly chute.

Because of the expected duration of the outage, arrangements were made for automatic juice sampling rather than resorting to hand sampling. The sampling cone was located under a hole cut in a juice trough. A pneumatic diaphragm pump and additional piping was installed to pump the sample juice back to the laboratory.

A temporary steam connection was made to allow the line to be steamed out manually. The only adjustment necessary to the sample tracking system was to increase the delay to allow for the longer juice sample lines and the additional conveyors between the tippler and the new first mill.

Figure 1 shows the general arrangement of the bypassed configuration. The factory was operated in this fashion for 10 days. The factory ran reasonably well in this mode although extraction was reduced because a mill had been removed from the tandem. An extra person was required to clean up around the belt conveying the cush and monitor its operation and to check the satisfactory operation of the juice sample pump.

Just over two shifts of lost time were incurred while number one mill was bypassed. This was an expensive exercise but at least the factory was able to continue operation.

Bypassing the mill avoided major factory downtime that would otherwise have occurred while the problem was rectified.

**Work done to investigate and rectify the problem**

The generally observable characteristics of the problem were:

- high speed gearbox operation noisy;
- general vibration around the turbine, particularly in the axial direction;
- axial vibration of the input shaft of the high speed gearbox;
- general vibration around the first motion pinion of the low speed gearbox.

A range of experienced sugar mill engineers, gear experts, failure analysts and consultants in machinery vibration diagnostics looked at the problem of the failing turbine shafts. The attempts to identify / correct the problem included:

- inspection of foundations for undue settling / vibration / cracking;
- inspection of holding down bolts for soundness;
- repeated attempts to realign the turbine and input shaft of the high speed gearbox;
- replacement of the coupling between the turbine and high speed gearbox;
- condition monitoring vibration measurements;
- replacement of the cone rings in the coupling between the high speed and low speed gearboxes;
- running the mill at different speeds and loads;
- impact frequency response tests;
- inspection of the profile of the first motion pinion of the low speed gearbox;
- blending out developing cracks in the turbine rotor shaft;
- crack testing the turbine rotor shaft;
- dismantling, inspection and rebuilding of the high speed gearbox under the supervision of representatives from a gearbox firm and a bearing supplier;
- lifting the cover on the low speed gearbox to inspect the gear mesh;
- replacement of the white metal bearings on the input shaft of the high speed gearbox;
- monitoring the intermediate shaft in the high speed gearbox axial vibration of the second motion shaft.

Despite these best efforts, three turbine rotor shafts were broken amidst raising frustration of all involved before some teeth broke off the first motion pinion of the high speed gearbox.

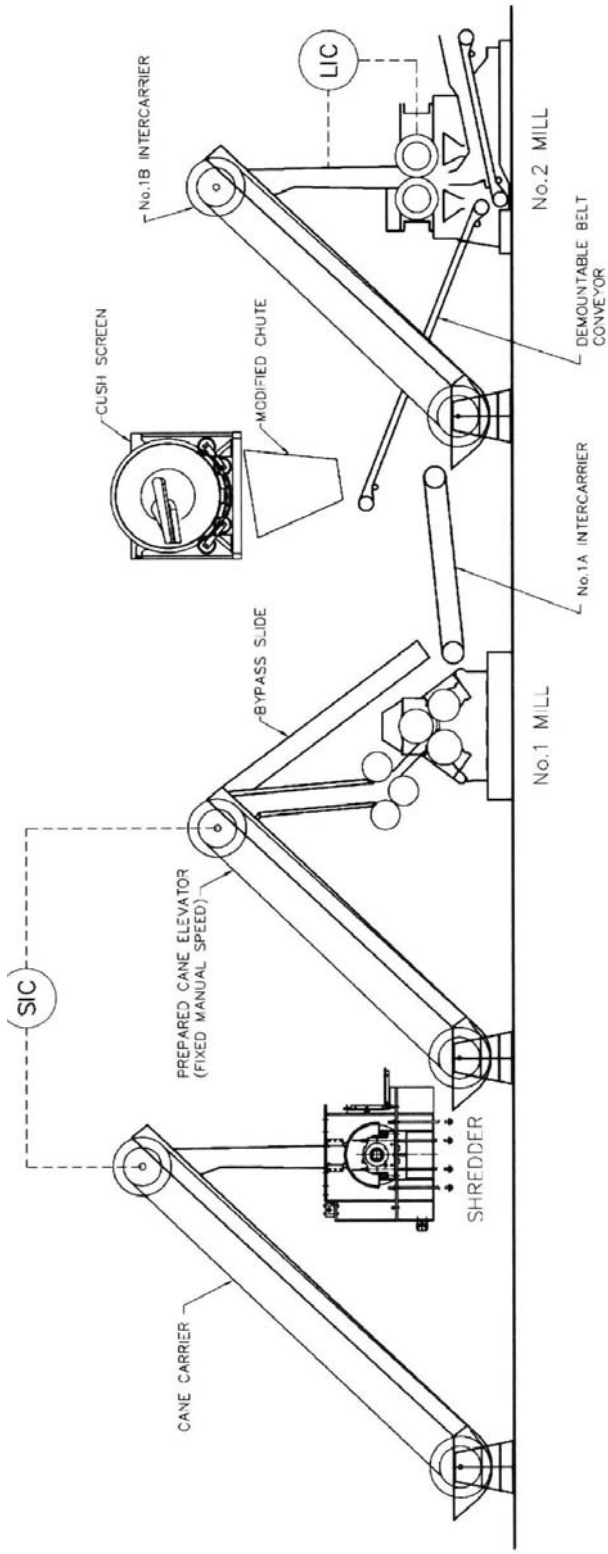


Fig. 1—Bypassed operation of number one mill.

Figure 2 shows details of the high speed gearbox fitted to number one mill at Bingera at the time of the problem. The output shaft of this gearbox was locked against axial movement by the locating action of one bearing. The intermediate and high speed shafts were free to float, relying on the centring action of the herringbone gears to maintain their axial position.

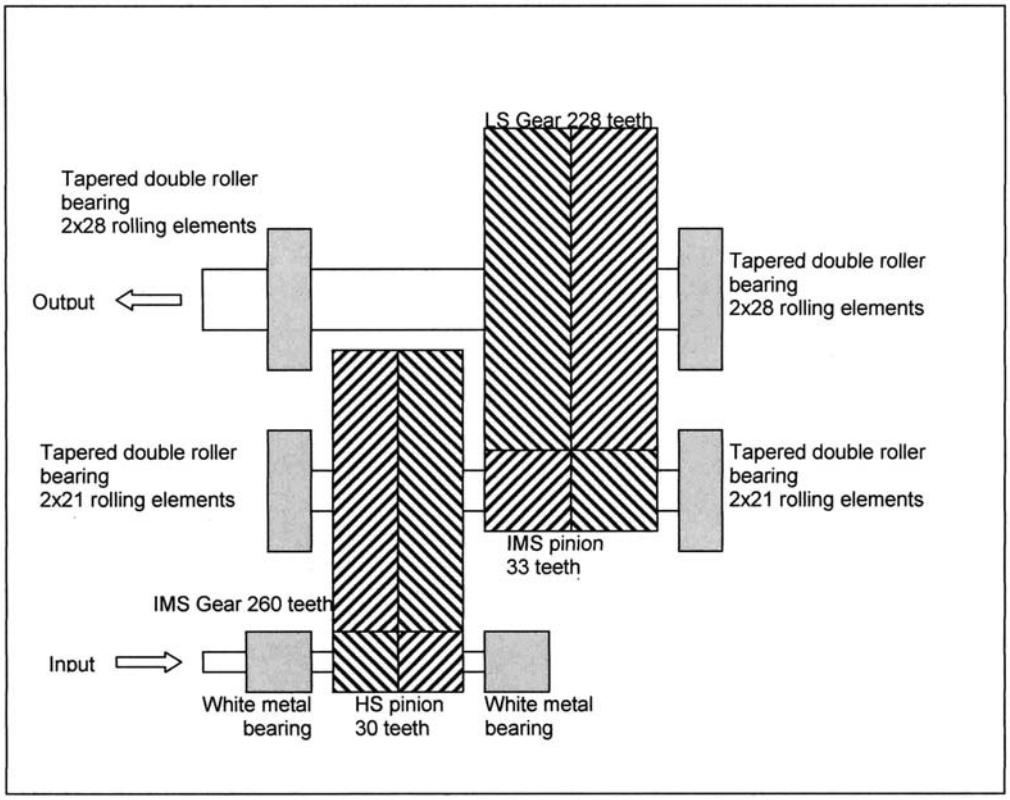


Fig. 2—Details of the high speed gearbox.

Vibration measurements indicated high axial vibration of the turbine shaft and the input shaft of the high speed gearbox. None of the frequency peaks in the vibration spectra related exactly to any shaft speed, tooth mesh or similar mechanical source. The closest match was the tooth mesh frequency of the first motion pinion of the low speed gearbox and a structural resonance of the turbine.

On a few occasions, minimal vibration occurred for a time after replacing coupling between the turbine and the input shaft of the high speed gearbox. A confounding aspect of the problem was how the high axial vibration of the turbine shaft and input shaft of the high speed gearbox were resulting in a fatigue failure of the turbine rotor shaft.

Bingera's number one mill high speed gearbox had a history of problems. Following refurbishment for the 1999 season, the gearbox exhibited a vibration problem, particularly at low speed under light load. At the start of the 2000 crushing season, the gears were recut and the alignment, clearances and fits checked. There still tended to be a vibration problem after

this work. Two independent gearbox firms assessed the gearbox vibration at the time and neither came to a firm conclusion as to the source of that vibration.

Following the failure of the input shaft pinion of the high speed gearbox in 2005, Bingera mill sent a request for assistance to all Australian mills. One factory responded with a very similar gearbox that had been made redundant shortly after refurbishment. The spare gearbox was nominally a sister unit though the ratio was a little more direct. The more direct ratio was desirable at Bingera as a means of allowing higher mill speed. The associated reduction in torque available at the mill was not of concern as the turbine had been upgraded from 560 kW to 750 kW in the past.

Closer inspection found that while the gearbox was a sister unit, it was a little newer and had been manufactured to metric dimensions whereas the old gearbox was based on imperial dimensions. The gearbox slotted in well with relatively few modifications. Particular attention was paid to the turbine / gearbox alignment when the replacement gearbox was fitted and a new splined coupling was fitted. The drive was free of abnormal vibrations after the high speed gearbox was replaced and has run two seasons without any sign of the problem recurring.

The failed teeth on the first motion pinion of the high speed gearbox showed evidence that the teeth on one side of the herringbone, at one spot around the gear, had been cracked for some time. It is hypothesised that these cracked teeth on the pinion created an effective soft spot that caused the input shaft to thrust once per revolution. It is further proposed that the coupling between the turbine and input shaft of the high speed gearbox was sometimes able to accommodate the thrusting (when the coupling was in good condition and the transmitted torque was low) and at other times was locked up and transmitted the thrusting to the shaft of the turbine.

**Conclusion**

The failure of the number one mill drive at Bingera Mill was a very expensive incident. The cost would have been much higher if it had not been possible to bypass the mill in a timely manner that retained the full functionality of the juice tracking and sampling systems. Bingera was also fortunate in the extreme to locate a spare, compatible gearbox that was made available.

Despite the best efforts of several experts, the true cause of the problem was not identified beyond all doubt. The most probable cause of the vibration is considered to be cracked teeth on the input shaft of the high speed gearbox. This explanation provides a means by which the rotary motion of the turbine and gearbox shafts could have excited axial vibration of the turbine shaft and the input shaft of the high speed gearbox.

Perhaps the best advice received during the investigation was to look to where the damage was occurring. This proved to be the case with the problem considered to be due to the coupled turbine and high speed gearbox input shafts rather than the holding down bolts, shaft alignment, couplings or assorted other possible causes considered during the investigation of the problem.