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M 18. ADVANCES IN HEAD DESIGN FOR LARGE SUSPENDED BATCH CENTRIFUGALS

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KEYWORDS: Suspended Fugal, Vibration, Unbalance, Structure

2012 ASSCT (Australian Societ of Sugar Cane Technologists) Conference

Abstract

A presentation, entitled "An Investigation of the Vibration Characteristics and Unbalance Tolerance of Large (1500+) Suspended Batch Fugals", was made at a workshop at the 2012 ASSCT conference. The material presented was insightful and demonstrated the need for improvements in the design of these centrifugals and the supporting structure.

Since the emergence of these issues some 10 years ago, the unbalance concerns identified in the presentation have been resolved in the larger Western States TITAN-Series batch centrifugals via a complete redesign of the head.

An implied premise that larger centrifugals inherently have undue vibration has proven to be inaccurate. A properly designed bumper-gimbal configuration can restrict dangerously large basket deflection and simultaneously provide the dampening required for stability. The design does not necessarily produce "stick slip" and other non-linear characteristics that prevent free articulation of the gimbal.

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Introduction

At the 2012 ASSCT conference, a presentation by Innisfail Scientific Services (ISS) summarised a portion of a report by ISS on an investigation into centrifugal performance at a sugar mill (Cramp and Yarrow, 2012). The presentation, in particular, addressed the head bumper and gimbal design. These components are essential for acceptable vibration response to unbalanced loads and also provide stability for very large unbalances and unstable liquid loads. The presentation notes seemingly conflicting requirements to meet these goals as the basket (drum) size becomes larger.

These items were identified and addressed many years ago by the Western States Machine Company. This document describes the measures taken to remedy these items in the current Western States batch centrifugal.

The data used for the ISS presentation were obtained from two, circa 1999, Western States Model 1750 centrifugals located at Mulgrave Mill. Initial vibration problems included: trip-outs, fatigue cracking and excessive motion. These problems led to the study by ISS Consultants. In their evaluation, ISS diagnosed a resonance problem near top speed and a fix was made by strengthening the platform. No mention of this fix was stated in the presentation; however the resonance elimination is discussed in their full report. It appears all of the data presented at the conference were obtained subsequent to this platform modification. The extent of continuing problems was not clear. However, a graph of vibration severity versus unbalance raised the question as to whether or not larger centrifugals are more sensitive in terms of the allowable percentage of product unbalance.

Sometime after the ISS study, a Western States engineer visited Mulgrave Mill. He reported that they had found superior gimbal grease for the 1750 centrifugals and that no further vibration issues were reported.

The experience at Mulgrave Mill parallels a similar occurrence at Tabacal Mill in Argentina. Two Western States model 1750 centrifugals of identical design to those at Mulgrave were installed at Tabacal in 2000. The two newly installed centrifugals had severe vibration issues; so much so that their operating speed had to be limited to 900 r/min during the first season. After evaluating the issue on site, Western States determined that the machine had a resonance problem at the top spin speed. Following the campaign, the platform was rebuilt with larger beams. The improvement was dramatic and normal operation to 1050 r/min was permitted. The vibration study conducted by Western States in South America led directly to improvements now incorporated in the latest TITAN design.

Discussion

ISS in their full report raise the question:

In the course of scaling up capacity, will the bumper configuration not work, because the bumper force, required to stabilise the low-speed wobble of a heavier basket, prevents the ball-seat to articulate?

This scepticism may leave one with the impression that larger centrifugals inherently have undue vibration. However, improved designs have conclusively shown these challenges can be overcome.

Cramp and Yarrow (2012) state that a suspended centrifuge should have two main facets:

- The pendulum action should be well stabilised to avoid large displacements
- Freely gimbaled to allow orbit adjustment to accommodate uneven mass loading

However, they warn that these are conflicting requirements. As fugal size increases, the compromise setting becomes harder to achieve.

In Figure 1, ISS graphically depicts a bumper-gimbal design.

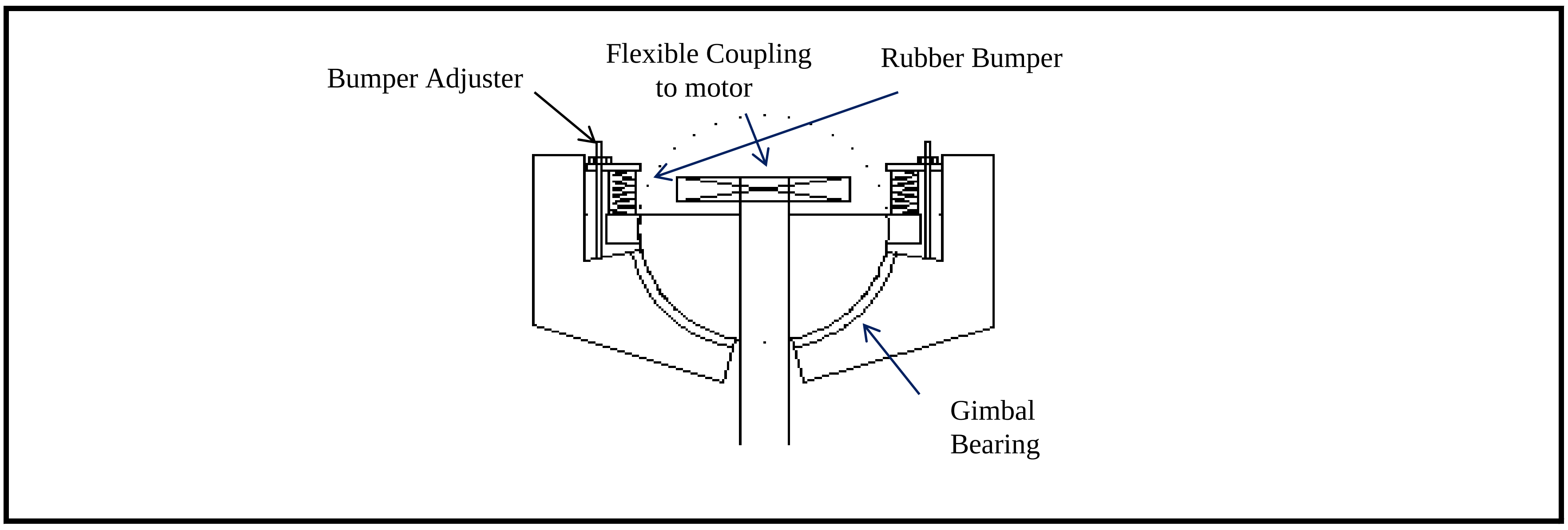

Figure 1: Schematic of fugal spherical joint (Cramp and Yarrow 2012)

Figure 1 identifies two conflicting requirements that become increasingly more difficult to address in larger-size centrifugals. The bumper must stabilise the large displacement of a heavier basket, but the gimbal should freely accommodate the wobbling motion of the spindle so that the suspended centrifugal can self-balance. The presentation expounds on the non-linear nature of the bumper-gimbal design. The non-linear contrarian nature of the bumper-tightness makes the gimbal action prone to “stick-slip” seizures. Furthermore, the non-linearity itself makes proper adjustment difficult.

The conclusions of Cramp and Yarrow (2012), pertinent to this bumper-gimbal geometry were:

1) “The bumper tension required to stabilise the centrifugal at low speed is hindering the self-balancing gyroscopic effects.”

2) “The grease lubrication is not ideal as it has a ‘stick slip’ effect.”

3) “The design of the bumper makes its adjustment highly non-linear.”

These same conclusions were identified by Western States' Engineers and led to a redesign.

The older G17 style head used at Mulgrave and Tabacal was superseded by an improved head when the TITAN-1750 was redesigned in 2003. The older G17 head design is no longer used. In the course of this redesign, particular attention was paid to the bumper and gimbal.

The presentation may leave the impression that the bumper tension is providing a hindering force that considerably impairs self-balancing. Actually, most of the unbalance is countered by the basket’s inertia which opposes the out-of-balance forces.

The basic principle of self-balancing is that the spinning parts rotate about the centre of gravity when the running speed is sufficiently above the pendulum frequency. It should be emphasised that the spindle-basket is offset slightly (0.3 to 1.3 mm) when self-balancing occurs. The offset is necessary -- otherwise there is no self-balancing. For example, in the test 5 kg of unbalance creates 46 KN force, – easily sufficient to overcome the hindering resistance. The result is that approximately 95% is balanced. The remaining 5% overcomes the bumper tension that is attempting to return the basket to the true machine axis. This small portion is the oscillating force, acting ultimately on the motor base structure, creating vibration.

With proper design and adjustment, the bumper and gimbal should hinder the self-balancing by a relatively small amount. Any improvement in self-balancing yields a large reduction in vibration.

This observation led to an important design goal. Basically, any improvement in gimbal articulation results in a dramatic change in vibration. For example, going from 93% self-balance to 95% self-balance reduces the unbalanced portion from 7% to 5%. This is a 28% lowering of vibration excitation. We were able to make improvements in the hindering, thereby reducing vibration. The path to these improvements lies in the conclusions given in the presentation.

Proper damping, not critically damped by over-tightening, contributes negligibly to additional vibration away from the pendulum frequency. Vibration amplitude is greatly affected near a critical, but not at top spin speed. Figures 2 and 3 from the ISS presentation illustrate this. The vibration is nearly identical between a tight and free-gimbal condition at top spin speed, but damping influences the amplitudes at 800 r/min.

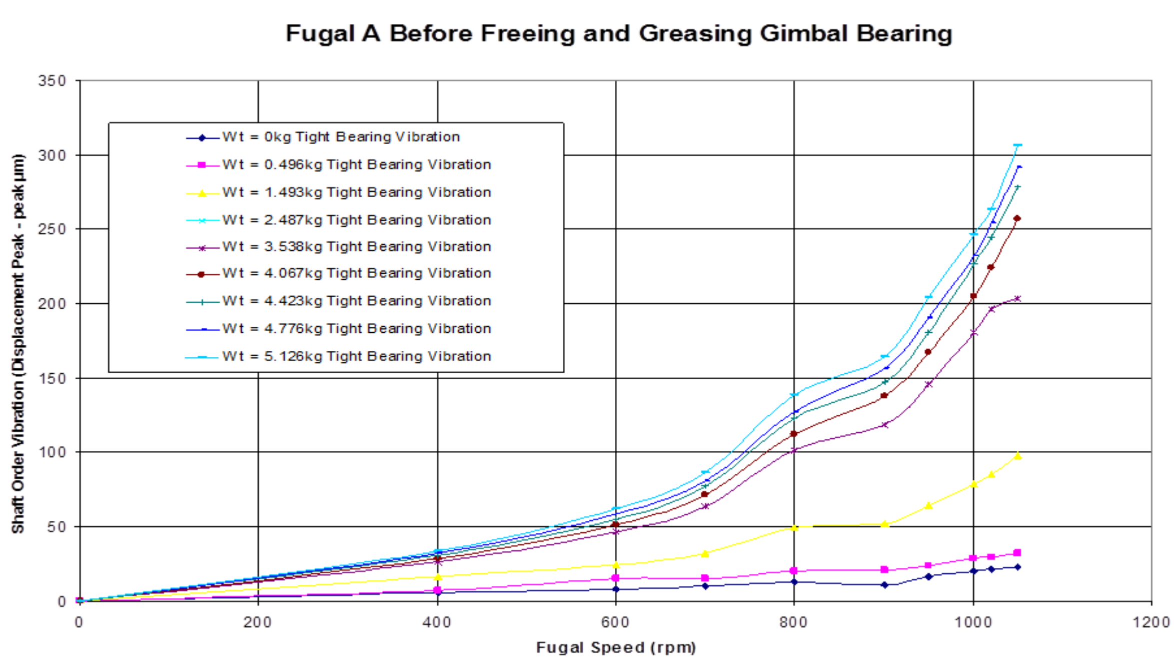

Figure 2: Fugal A before freeing and greasing gimbal bearing (Cramp and Yarrow, 2012)

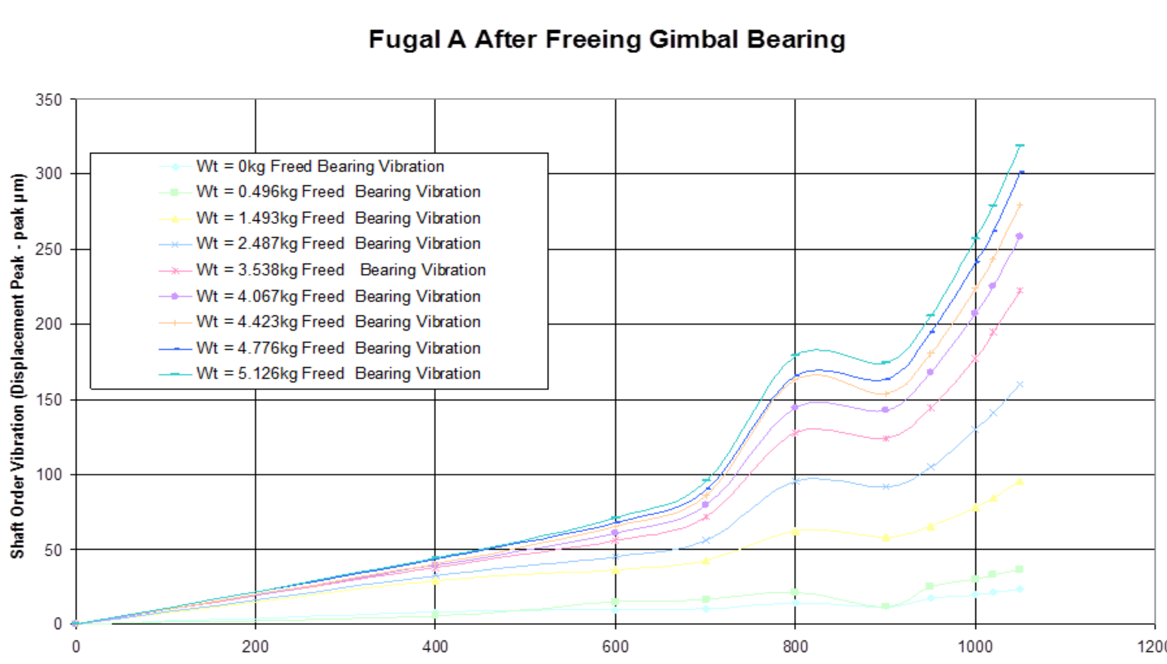

Figure 3: Fugal A after freeing gimbal bearing (Cramp and Yarrow, 2012)

Improper damping, on the other hand, is extremely detrimental. A too-tight or non-lubricated gimbal definitely runs poorly. The unbalance is insufficient to permanently prevent momentary seizures. Even with minimal unbalance, any seizure intermittently forces the ball-bearings to act as the pivoting means, rather than the gimbal. As a result the basket spindle movement, though small, will have a characteristic "jerky" impact-like motion.

The G17 had followed the industry trend of making the head more compact. Like our competitors, the bearings became closely spaced. Test measurements verified that making the bearings more closely spaced aggravated misalignments, thereby contributing to the afore-mentioned jerkiness. This led to the G17 requiring tighter bearing specifications.

Rather than reinventing the wheel and overcoming unnecessary challenges, it was decided to look back to an older proven design, the Western States G8. With several thousand installations worldwide, the G8 had established a reputation of being able to handle difficult product loads. To emulate this design and make it suitable for a new larger series (TITAN-1900 and TITAN-2400); more would be required than simply larger capacity bearings and bumper.

The geometry had to be completely changed so as to avoid the G17's non-linear bumper behaviour. The gimbal pressure angle was improved to lessen any self-locking tendency, and the bumper was no longer in such a confining enclosure which had previously been preventing linear shear distortion of the bumper. The new design avoided any inherent tendency to over-tighten the pivoting mechanism and lessened the propensity for "stick-slip" momentary seizures.

In keeping with the proven G8 geometry the bearing spacing was lengthened. The upper angular bearing of the G17 was identified as a weak link. This bearing was replaced with a heavy-duty spherical roller bearing – like the G8 -- having many times the rigidity of the angular one. The result was much better alignment leading to the motor coupling. The motor coupling itself was improved with larger, more compliant rubber components.

The new head was designated the G20. The more rugged design of the G20 head can be observed in Figure 4. The G20 provides a more-forgiving, steady articulation.

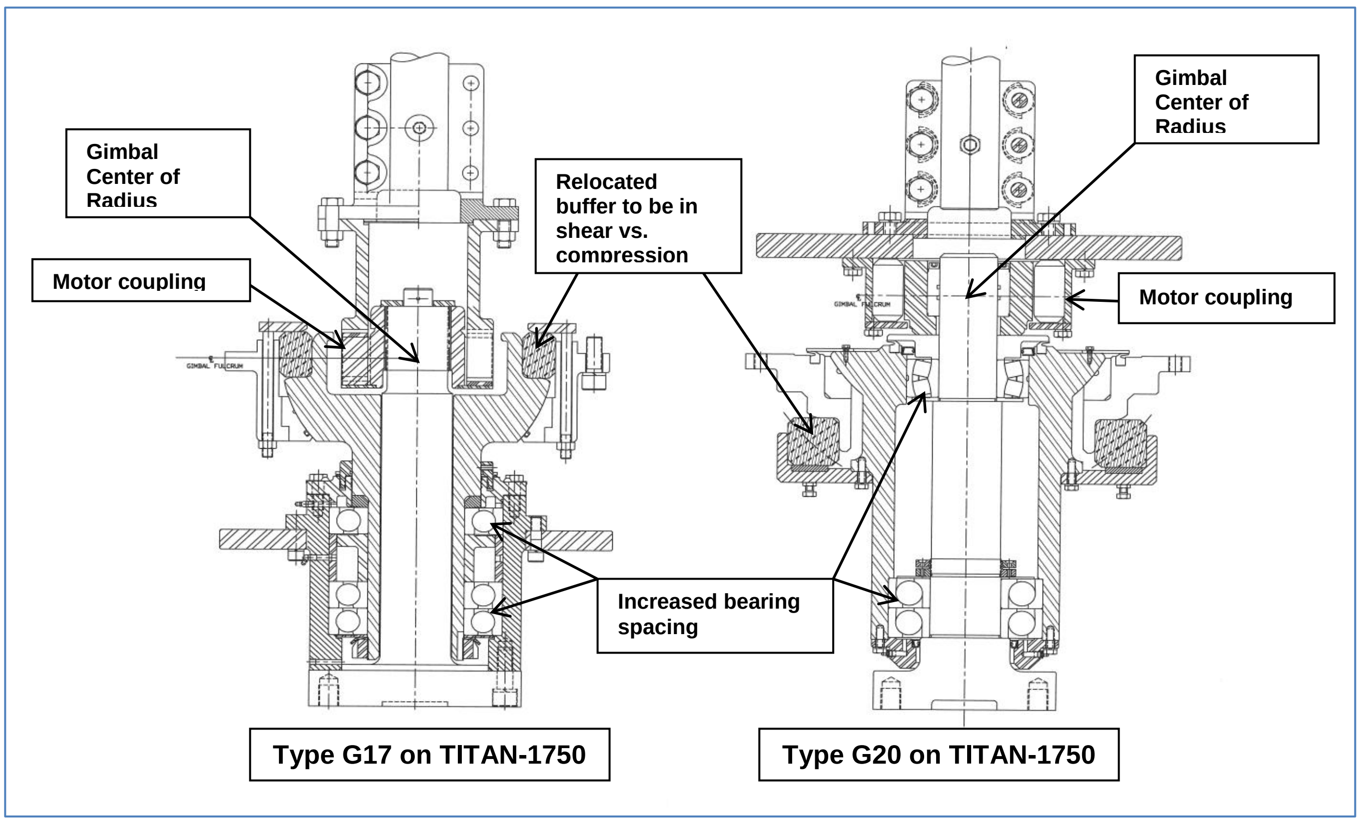

Figure 4: Comparison of G17 and G20 head designs

Most importantly, there are a host of other factors governing vibration levels and stability. For the largest size basket, 72" x 45" (TITAN-2400), a more effective basket height-to-diameter ratio was used for better gyroscopic stabilisation. This has proven to be a very stable design in the field. In fact, when utilising the improved G20 head, the larger TITAN-2400 is just as stable as the TITAN-1900 due to its basket height-to-diameter ratio. This factor has shown to be an additional important consideration in the design of larger centrifugals.

Along with the aforementioned improvements, changes were also made to the machine structure. A larger diameter spindle and stronger enclosed-box-construction columns were used on the A-frame. These improvements were all a result of the lessons learned from the machine diagnosed in South America.

Conclusion

Problematic installations, at Mulgrave Mill in Australia, and Tabacal Mill in Argentina, led to a thorough evaluation and the subsequent development of an improved head design for Western States' larger pendulum style batch centrifugals. The industry trend of making the head more compact was shown to be a mistake. By relocating the bumper so that it operates in shear versus compression and by lengthening the distance between the bearings; the new G20 head avoids the tendency to over-tighten the pivoting mechanism and lessens the propensity for "stick-slip" momentary seizures. The new G20 design provides a vast improvement in limiting vibration and dispels the notion that larger centrifugals are inherently unstable. It has also proven to be durable and maintenance free. Because of its superior performance, the G20 has become the standard on all larger TITAN-Series batch centrifugals.

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