DESIGN REVIEW OF GEARLESS MILL DRIVE: MILL SYSTEM ANALYSIS

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Abstract: It has been well established that a critical component of the up-front design for large mills is a full system Finite Element Analysis (FEA), including the mill and its bearings, the motor, the foundation and the soil. The mill body, stator and foundations form a complex structure which responds dynamically to the harmonic and transient forces. If not designed correctly, damaging responses in the form of resonance, non-linear sub-harmonic oscillation or excessive transient motions can occur. These could lead to loss of air gap (stator rub) or overstressing of structural components. Important to understand the risk of Anglo American if different Suppliers, separately supplying, a combined solution. Examples of these are complete mil systems, conveyor and structures, screen and structures, etc. The paper will give feedback on the review process and the importance of suppliers understanding Anglo American risk.

Keywords: Gearless Mills, System Analysis, Risk

1 BACKGROUND OF GEARLESS MILL DRIVES

Mills in general are found in the processing plant of commodities like platinum, copper and others. They are used to reduce the particle size of ore and forms part of the critical chain in the process plant. Historically smaller mills (with diameter maximum values of about 10 meter (34 feet)) have been driven by geared systems. A large ring gear is placed on the outer layer of the mill shell and driven by an electrical motor with gearbox and pinion. The size of the shell was basically constrained by the difficulty to manufacture a ring gear of larger and larger diameter. Figure 1 shows a gear driven mill.

Figure 1: Gear Driven Mill
Gearless Mill Drives (GMD) was first used in the cement industry in the late 1960s but have progressed to the mineral industry due to their possibility to increase the size of the mill significantly relative to the gear driven mill. This produces a “grinding economies of scale”, the relative lifecycle cost is lower due to less wearing part (no gears involved), lower power consumption due to less friction in the system, availability increased and minimum downtime (Dugalic and Tischler). The sheer size of the mill shell is increasing steadily with operating mill having diameters of 12.2 meters (40 feet) and currently a mill being ordered with diameter of 12.8 meters (42 feet), 28 Mega Watt motor, expected to operate in late 2014, early 2015 (Orser, et al). Figure 2 shows a gearless mill.

Figure 2: Gearless Mill

In previous large capacity plant designs, the production rate probably require pairs of gear driven mill that have significant capital investment consequences as well as the increased maintenance cost. With the gearless mill it is now possible to reduce the number of mills by increasing the mill size and thus reduce capital investment, maintenance is reduced due to the technology used and operation cost is also reduced due to the machines efficiency.

This sound very attractive to any plant operator, capital cost can be lowered, operation cost is lower, and efficiency and availability are increased.

2 ARE GEARLESS MILL DRIVES THE SO CALLED “HOLY GRAIL”

The benefits seem to be attractive and a no-brain answers. This is true when the risks involved are well understood and managed. The major risk with GMDs is that a total failure of the mill easily leads to forced operation shut down. Serious failures are usually difficult to repair and thus time consuming; this simply means the plant will stand for a longer time. From a safety point of view: The sheer size and mass of the mill rotating also means that a huge amount of energy is stored in the system, and we also define risk as a function of the amount of energy involved in a process. Nobody wants a mill shell running loose in year plant or mine.

To put these two simple risks into perspective, we compare the most significant mining industry property losses between January 2006 and July 2009 in Table 1 (Dugalic and Tischler).
Table 1: Significant Mining Industry Property Losses (Jan 2006 – Jul 2009) (Dugalic and Tischler).

<table>
<thead>
<tr>
<th>Class</th>
<th>Loss Type</th>
<th>Gross Claim (millions of US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Flood</td>
<td>+/- 603</td>
</tr>
<tr>
<td>Coal</td>
<td>Flood</td>
<td>+/- 550</td>
</tr>
<tr>
<td>Coal</td>
<td>Flood</td>
<td>+/- 450</td>
</tr>
<tr>
<td>Iron</td>
<td>Strom/Flooding</td>
<td>+/- 180</td>
</tr>
<tr>
<td>Manganese</td>
<td>Smelter Explosion</td>
<td>+/- 170</td>
</tr>
<tr>
<td>Platinum</td>
<td>Flood</td>
<td>+/- 140.3</td>
</tr>
<tr>
<td>Iron/Salt</td>
<td>Typhoon (Glenda)</td>
<td>+/- 122.4</td>
</tr>
<tr>
<td>Copper/Zinc</td>
<td>Electrical Flashovers of SAG Mill Stator</td>
<td>+/- 115</td>
</tr>
<tr>
<td>Iron/Salt</td>
<td>Typhoon (Emma)</td>
<td>+/- 107.7</td>
</tr>
</tbody>
</table>

Table 1 clearly indicates that a significant financial risk is involved when making the decision to go Gearless; basically you have all your eggs in one basket.

3 HOW DO WE MANAGE THE RISK, FIRST UNDERSTAND WHAT IS AT STAKE?

To manage the risk we firstly need to understand what is involved, especially in such a complex system. The gearless mill design is dependent on a combination of engineering disciplines, technologies and controls working together to ensure safe and successful operations of the mill.

The GMD is basically a large electrical motor. The Stator is a large structure containing copper windings. These windings are energized electrically to produce a magnetic field. A cycloconverter is used to reduce the supply voltage frequency to a much lower frequency. This lower frequency is fed into the stator windings and a rotating magnetic field is generated in the stator.

The Rotor part is the shell of the mill. All the grinding material is processed by this revolving rotor shell. Internally the shells have a large amount of wear liners to protect the shell lining and increase the efficiency of the grinding process. Rotor poles are connected to the shell structure. The rotor poles are energized electrically, this produce a magnetic field.

The rotating stator field interact with the rotor field and produce a large amount of torque at slow speed, about 10 rpm. To put this in context – a Gearless Mill can be rated at 22 Mega Watt, but the rotating speed is only 10 rpm. The torque generated can simply be calculated by equation 1.

\[
\text{Power} = (\text{Torque}) \times (\text{Rotation speed})
\]  

(1)

Comparing this Gearless mill with motor typically used in power generation, running at 1500 rpm but at significantly higher power outputs shows that the gearless mill is basically equivalent to a 6.6 Giga Watt machine running at 1500 rpm. The largest motor running at 1500 rpm is currently about 1.2 Giga Watt. The catch is that the Gearless mill produces a huge amount of torque, at lower speed, thus putting this mill technology in a class of its own. The torque needs to be contained from structural point of view, thus the requirement to ensure that structurally the machine will be able to withstand the forces and torques applied to it.
The mill rotor is driven by the energised stator through an air gap. It is of critical importance to manage the gap between the rotor and stator to a very fine tolerance. The nominal air gap is typically 20 mm. The air gap is typically allowed to vary between 4 and 6 mm (depending on the status of the machine). This variance includes the tolerances of thermal expansion, structural changes due to rotor load, electrical tolerances in the magnetic field generated, etc.

The magnetic force between the rotor and stator basically acts as an “inverse spring”, the closer the rotor and stator moves to each other the higher they attract one another. This basically means that the structural stiffness of the rotor, bearing housing and stator must be sufficient to withstand the forces generated by “inverse magnetic spring”.

What is the consequence if stator and rotor touch under electrical load (rotor rub)? Simple the electrical insulation of the windings becomes so hot that the coil’s insulation melts due to the heat build-up and melts the copper windings. These need to be replaced and hopefully the machine does not have significant damage, but in short basically allot of downtime.

Engineering disciplines involves in design, controlling, manufacturing and operating a gearless mill are as follows (but not limited to):

- Electrical engineering – to understand the electrical control of machine and energies involved in turning the stator
- Electronic/Control engineering – to understand the control of the machines using the latest controller hardware, software and control loops
- Mechanical engineering – understanding the structural response, fatigue, vibration, forces interacting between stator and rotor, rotor and bearings, bearings and foundation, stator and foundations, brakes system, etc.
- Civil/Structural engineering – understanding the foundation from static but also dynamic response point of view, interaction between all the components with the foundation and also contribute to ensure structural integrity of the stator, rotor and bearing.
- Geotechnical engineering – the soil plays an important part, especially for such a heavy structure. The static and dynamic response of the system can be influenced by the quality and stiffness of the soil.

4 WHAT OTHER RISK ARE INVOLVED?

1.1 Communication

Another risk to the Gearless mill is hidden from the obvious technology used, but plays a significant role in the success of these complex machines. The risk involves the roll players/Suppliers. The problem is that a machine as complex as a Gearless mill is usually not designed, manufactured, erected and commissioned by one Supplier. It’s a combined effort that involves allot of contractual, legal and commercial risk between different Suppliers. These risks can become so complex that it may even overshadow the “simpler” engineering risk. To understand the risk involved a simple design process of a component is depicted in Figure 2.
Each Supplier takes responsibility of one part of the entire structure. The Supplier is responsible to manage and complete the design process associated to its part. Most of the parts however require input from other Suppliers to ensure that the machine will actually be capable of working as a system.

Communication between Suppliers are thus of utmost importance. But this communication needs to be managed and sometimes prompted to ensure that it actually takes place. For instance, the Supplier of the foundation need to be aware of any changes done in the design of the stator connection bolts, as well as the rotor bearing support structure. Any changes in the loads generated by the stator and rotor also need to be considered by foundation Supplier.  

Communication is required between all parties, at least, at each stage of the design process. It may even be required to run full system analysis every time major changes are made to the design, more on this in Section 4.2. This is to ensure that required information is exchanged and updated between companies. It also ensure that different Supplier understand the influence of design changes on other Suppliers and on the system itself. If the design process of Figure 2 is followed the design is setup for failure, this is due to parties only communicating at the beginning of the process and then again when the system is commissioned.

If communication is not managed correctly it is possible to end up at erection or even commissioning and find out that one system can’t fit to another or that the system can’t work in combination. This obviously have a significant cost implication if, as in most cases, the completion of the mills are in the critical path of a project.
1.2 Combined Analysis

Computer Simulation Models are used to assist the design team (per Suppliers) to ensure the product that will eventually be delivered have a better probability of surviving the assumed loadcases. Different types of analysis can be performed; from a Mechanical/Structural point of view the most relevant analysis is structural Finite Element Analysis (FEA). The FEA provide detailed results of the displacement and stress distribution that is generated by the assumed load and boundary conditions. The results can be used to ensure the structure will be stiff enough to handle the assumed loads and to predict if the structure will last the required fatigue cycles, based on specified criteria of the predicted lifecycle of the machine.

The assumptions made during these analyses are of utmost importance since these drive the results of the simulation. Assumptions are usually made “inside” each Supplier’s design team of what loads and boundary conditions exist on the part of the mill. Some of these assumptions also include how the other Suppliers components will interact and influence their own design.

One major assumption that has a significant influence is how the soil and foundation interact with the rest of the structure. Structural vibration is dependent on the mass and stiffness of the entire system. It is of utmost importance that operational frequencies and natural modes (natural frequencies) does not coincide. Significant damage can be done to the mill system if it is excited at a natural frequency, this effect the life, operation and structural integrity of the entire system. It is thus of utmost importance that a cross check or combined simulation is performed taking all the parts into account. These analyses should, at least, include investigation into basic structural integrity (static or dynamic response of the system) as well as vibration analysis to evaluate the modal response of the system.

One of the tricky engineering aspects of the GMD system is a possibility of a dynamic interaction between several parts of the system. In most cases, where excessive vibration and complete failure has been experienced, dynamic interaction was suspected. This phenomenon is usually defined by excessive vibration levels usually in the direction different to the direction of the operational forces. When systems of the GMD are designed independently, the risk of a dynamic interaction is almost certain. The components designers make use of assumptions to define the initial and boundary conditions to commence with the design. These are usually not fully comprehended by other designers. Stiffness and mass requirements are not fully defined and thus not met. A well developed numerical analysis models such as finite element is used in the systems model to define the stiffness and mass properties of different components in a single environment. An accurate behaviour of the system can thus be made and any potential problem identified.

This combined simulation provides the unique opportunity for all role players to witness and understand the influence their own system has on the global response of the system. These system analyses should form part of the design process as it will ensure that design teams with different objective from different Suppliers get together and have a virtual look at system response. This does not only apply to GMD but any system that interact across suppliers or across engineering disciplines. The model does not have to be structurally focused but can contain many of the engineering disciplines interacting.

It is also important for the Client to play an important role in the setup and review of these analyses, most importantly in the areas where assumptions like boundary conditions and loads are agreed upon. The Supplier does know the equipment but the equipment will be in the hand of the Client almost its entire life span. The Client also has experience in the working environment that the equipment will function. Typical examples are the influence of dust, water, weather, height above sea level, earthquakes, man machine interfaces, etc. The Client thus needs to discuss and be involved in the engineering process to ensure the product will be successfully operated during its entire expected lifecycle.

Advances in simulation software allow the user to drive multi disciplinary and multi physics analysis on larger and larger scales. If used correctly the engineering risk of multi disciplinary field interacting can be greatly reduced. The fact that a Supplier is not used to, or did not do these analysis in the past is no reason for then not to push the boundaries of engineering, to have a better understanding of how their system interact on a greater scale. The cost involved and risk associated with the large machine not performing according to requirements, should be clear drivers to make use of new technologies to better understand design earlier-on in the design process and by doing this reducing risk of unknown factors and interactions.
5 CONCLUSION

The application of gearless mills in plants is on the increase with the expectation of better production at lower cost due to more efficient machine. These benefits are attainable with the team involved ensure that risks are correctly managed. Risk on these complex machines includes (but not limited to) engineering and contractual risk with different Suppliers involved. The project leader should be aware of the complex nature of these machines and have a team to support him from all different disciplines, not only engineer but contractual and legal. The success of these mills (and other complex systems) are based on a multi disciplinary team working together with one goal, to ensure the mills as a system is successfully commissioned and operated over the estimated life span. The team should comprise of members of the different Suppliers as well as Client representatives with their different fields of expertise.

6 REFERENCES

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