Reference Information Document

Mill Starting Evaluation Report:

Version 102

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Document No

LRS_Reference Document_V102

Date

27 October 2021

Title

Reference Information: LRS Evaluation Reports

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Purpose of this document

This document is intended to provide more detailed information when a report is presented by SDG Technologies once a start-up test has been done and the performance of the LRS been evaluated

There are several possible performance defects on LRS's which can cause long term mechanical damage to girth gear and pinion, gearbox, bearing and couplings. It can also lead to electrical failures like slip-ring flashing and reduced motor life.

The following aspects are being addressed and explained in more detail

- Torque spikes being generated during a start-up cycle and the effect thereof
    - The various limits for torque spikes are being provided and explained
- What factors control the torque spikes and what can be done to remedy or control it.
    - Controls such as temperature controls to ensure starting torque within range by making use of heaters and coolers.
- The importance of continuous monitoring as the performance of the LRS change over time

- Electrode deterioration being the major factor in causing performance change are being explained and what is causing the electrode deterioration.
- The major factor for causing electrode deterioration is contamination of the electrolyte and information are being provided how to limit the contamination and the subsequently the deterioration. Two apects being explained are the use of Demineralised water and using filters to keep dust and unwanted minerals away from the electrolyte.

- The means provided by SDG to do continuous monitoring such as:
  - Ad Hoc testing and evaluation with portable testing and measuring equipment
  - Ad Hoc testing making use of partially installed components as a cost saving exercise.
  - Continuous monitoring of every start with an installed system from SDG Technologies called the Mill Safe Start System

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Amendment History

Rev	Date	Details	Distribution
1.0	2021/10/19	Starting Evaluation: Information Reference Final Report V1.0 report	
102	2021/10/27	Revision	

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1. INTRODUCTION

SDG specializes in testing Liquid Resistance Starter (LRS) performance since 2005

For more information on SDG Technologies, please refer to the section called "Introduction to SDG and Mill Safe Start".

For more information on the calculations used, please refer to the section called "Method".

For an explanation of acronyms used, please refer to the section called "Definitions and Abbreviations".

Bad LRS performance has a well-documented long term detrimental effect on mechanical and electrical reliability of mills. (Ref1)

A good LRS that is well looked after and monitored, can provide trouble-free reliable starting of a mill with torque transients not much higher than normal running operation. While generally robust and reliable, it is advised to periodically measure the performance of LRS's with start-up tests to determine the torque spikes inflicted on the drive system.

There are several possible performance defects on LRS's which can cause long term mechanical damage like girth and pinion gear cracking, gearbox problems and bearing problems. It can also lead to electrical failures like slip-ring flashing and reduced motor life.

2. INTRODUCTION TO SDG AND MILL SAFE START

SDG Technologies was established in 1999 and specializes in testing Liquid Resistance Starter (LRS) performance. We have been involved for many years in numerous investigations and remedial action where inadequate LRS performance was responsible for damage resulting in mechanical failure. Clients include numerous mining companies (for example Glencore Xstrata, Goldfields, First Quantum Minerals, Anglo Platinum, Oceana Gold, Zimplats, etc) across many countries such as Ghana, Zambia, Zimbabwe, Guinea, Philippines, South Africa, etc..

The extent of the mechanical failures caused by bad LRS performance varies greatly depending on frequency of starting, quality of the mill manufacturing and safety factors in mill design.

Mechanical defects may show up quickly, but often only years after commissioning, which include girth gear cracking, pinion gear shaft shearing and gearbox vibrations.

The high torque transients caused by an underperforming LRS stresses the mechanical drivetrain on each start-up, causing any latent manufacturing imperfections to show up. At low start-up frequencies, it is possible that an underperforming LRS may not have an effect on the mechanical reliability during the working life of the mill.

This is an unnecessary risk to take, because the cost of ensuring good LRS performance is trivial compared to the cost of mechanical failure. Some LRS problems can also cause electrical failures, like slip-ring arcing.

To evaluate LRS performance, SDG records rotor currents and voltages during a full load start-up and evaluates the LRS using specially developed hardware and analysis software. The tests are quick, with minimal production loss.

All equipment can be safely connected while the mill is running, although it is normally done once the mill has stopped. The mill is stopped under full load conditions and started again immediately. The equipment may be disconnected while the mill is running. The only production time lost is therefore a single mill stop and start, if the safety procedures on site allows.

A torque trace (air-gap torque) is produced, as well as the expected motor shaft torque on a typical mill including the effects of mechanical system transient response (overshoot) and backlash. This is then compared to the recommendations of the Anglo Specification 581006 “Torque Limits for Grinding Mill Drives”.

The main product of SDG Technologies is the Mill Safe Start dropped charge protection and LRS monitor which records each and every start-up and uploads it to a server, where torque traces are generated in pdf format. This report is emailed, monitored by SDG and available online. As all information is available on each start-up, this allows trending of the LRS performance and also immediate notification if something goes wrong with the LRS.

3. METHOD

Liquid Resistance Starter (LRS) technology is an old and proven technology which has not evolved much over many years. However, mill sizes have become ever bigger. Generally, mills of higher power seem to be more susceptible to torque transient damage. The absolute performance figure of a LRS is called the turn-down ratio (TDR) and remained at a typical value of 50:1 or worse for many years even though the mill power was inching up.

Anglo Technical Division (ATD) in collaboration with FLSmidth developed a specification AAC Specification 581006 (Ref 2) to address failures experienced on their fleet of five 10.4MW dual-pinion mills at Rustenburg. This imposes a very strict limit on the maximum torque transient allowed on grinding mills.

SDG has been involved with these measurements and numerous other cases thereafter, and apply the principles of this specification during evaluations.

The air-gap torque (Tag) can be calculated from the rotor current. This is the torque exerted by the electrical field on the motor rotor. This is under the control of the LRS and is therefore the parameter that must be evaluated and modified if necessary. The torque exerted by the motor shaft on the rest of the drive train is related to this torque by the mechanical system response. The motor inertia reduces the torque transient, while backlash and linear system response amplifies the torque transient. After substantial Matlab modelling on different mills, comparison with motor shaft torque measurements and consultation with mill manufacturers, Anglo Technical developed the specification for LRS performance AAC 581006. If the LRS adheres to this specification it will not produce torque transients sufficient to damage to the biggest geared mills, even when started several times a day.

At the time of the publication of the specification, the preferred manufacturer of LRS's for Anglo Platinum (RWW) did not have a starter that could meet the specification, with their best LRS achieving a 50:1 turn-down ratio. A multistage starter configuration was therefore implemented on the biggest mills within Anglo Platinum providing a very high turn-down ratio of 400:1. In the mean time, RWW has introduced a new starter family of 100:1 ratio LRS's which are adequate for application to the bigger grinding mills.

The evaluation methodology followed to determine the Equivalent Shock Load Torque (ESLT) is to multiply the air-gap torque transient content that has a rise-time of quicker than 100ms with a weighing factor, and then compare it to a level.

AAC 581006 multiplies the >10Hz components with 2x and compares it to 2x the torque rating of the mill. It recommends that the ESLT should not exceed 200% of the torque at rated power.

For general application, SDG multiplies the first step with 1.8x and transients thereafter with 1.5x. This trace (ESLT) is then compared to the gearbox rating, or else generally with the % of rated torque of the motor. An ESLT exceeding 300% generally causes serious mechanical problems due to LRS underperformance. We therefore recommend improvement wherever we find the ESLT exceeding 300%, as a rule of thumb. Of course, lowering it to below 200% as recommended by AAC581006 is even better. Where the start-up frequency is high or where the mechanical drive train is already compromised, it is desirable to keep within the AAC581006 spec's recommendation to extend the working life of the mill drive train.

4. ELECTROLYTE TEMPERATURE EFFECTS

4.1 Explanation

The temperature of the electrolyte affects its conductivity therefore affecting the start-up torque which is being determined by the electrolyte conductivity.

The conductivity meter compensates its conductivity reading for the temperature, reading it as it would be at 25°C. It is therefore not a true reflection of the conductivity as it varies with temperature, but rather of the total kg of Sodium Carbonate in the tank. If the conductivity on the meter remains the same at a high temperature, it is not an indication that the Start Up Torque is going to be OK.

The start-up torque Tag at Temperature of 25°C is used as the reference Tag0 in the formula that expresses the change in Start Up Torque as a function of temperature, as follows:

$Tag = Tag_0\,(1+\theta\Delta T)$
where $\Delta T = T - T_0$

Tag is Start Up Torque at a temperature T
Tag_0 is the Start Up Torque at a specific temperature T_0 = 25°C
θ is the temperature coefficient of conductance of Na_2CO_3, which is 0.0265 if a reference temperature of 25°C is used.

With this formula, it is now possible to plot the Start Up Torque and the Starting Spike for different temperatures, if only a single Start Up Torque has been measured. The Start Up Torque is plotted in dark blue, while the Starting Spike is plotted in light blue.

This means that the exact temperatures where it is safe to start can be found. **For different electrolyte strengths this will be different. In the evaluation reports, the safe temperatures for the electrolyte strengths as it is found are being plotted. However, note that if the electrolyte strength is changed, the safe temperatures will change!**

The specification AAC 581006 “Torque Limits for Grinding Mill Drives” advises that the torque spikes should be kept below 200%. As explained, the Starting Spike is directly proportional to the Start Up Torque, but typically about 1.8x as big. For the Starting Torque to remain below 200% is therefore very difficult, as it means that one should not start up above 200/1.8 = 111%.

Three temperature points are noted for starting in the reports:

1. The temperature where the Start Up Torque falls below 110%. It is dangerous to start cooler without compensation.
2. The temperature where the Start Up Torque is 130%, which is the start-up torque normally recommended for wet milling applications of no electrode movement compensation is employed.
3. The temperature where the Start Up Torque is 140%, which is the maximum start-up torque normally recommended

5. WHY FIT HEATERS IF YOU ALREADY HAVE A HEAT PROBLEM?

It may sound counter-intuitive to recommend fitting a heater when you have heat problems on an LRS, and therefore the basics are quickly covered here to explain it. This is the most basic way to control the temperature.

SDG perceives that there is a lack of interest in implementing proper temperature control due to perceived cost, yet the cost of implementation of this option is negligible.(usually <R10 000).

The main problem with the LRS heat is not a too high temperature, but a too wide temperature range….. A wide temperature range corresponds to a wide range of starting torques. So except if the temperature happen to be in the middle, you will always be starting too high or too low.

If the temperature was always at the same high value, SDG can tune the electrolyte so that the LRS can give a perfect start at this high temperature, no problem. The aim is to limit the temperature variation to within a 10°C band.

The LRS cools down through natural convection, if no additional cooling is fitted. The hotter the water the quicker it will cool down. The important thing is the difference between the LRS water and the ambient. If we can ensure that the water is always at around the hottest ambient temperature experienced, it will always cool down by itself after a start-up after some time.

The important thing is that this removes the requirement to be able to start at a low temperature. Therefore we can tune it to start correctly at the high temperature and not worry about the low end.

Hand-in-hand with this solution is that the control system should only allow the LRS to start within the acceptable band of temperatures. (Or this can be done with thermostats if needed.) If the controlled temperature was selected high enough, the LRS will always cool down, and if the temperature goes beyond the maximum temperature, it is only a question of waiting a while for the LRS to cool down. At a low start-up rate this is acceptable.

The starts-per-hour may be improved further by adding a small air-blast cooler that takes the LRS water directly, without need for heat exchanger or cooling water.

The solution has the following draw-backs, which are seen as small compared to the huge improvement in starting torque range:

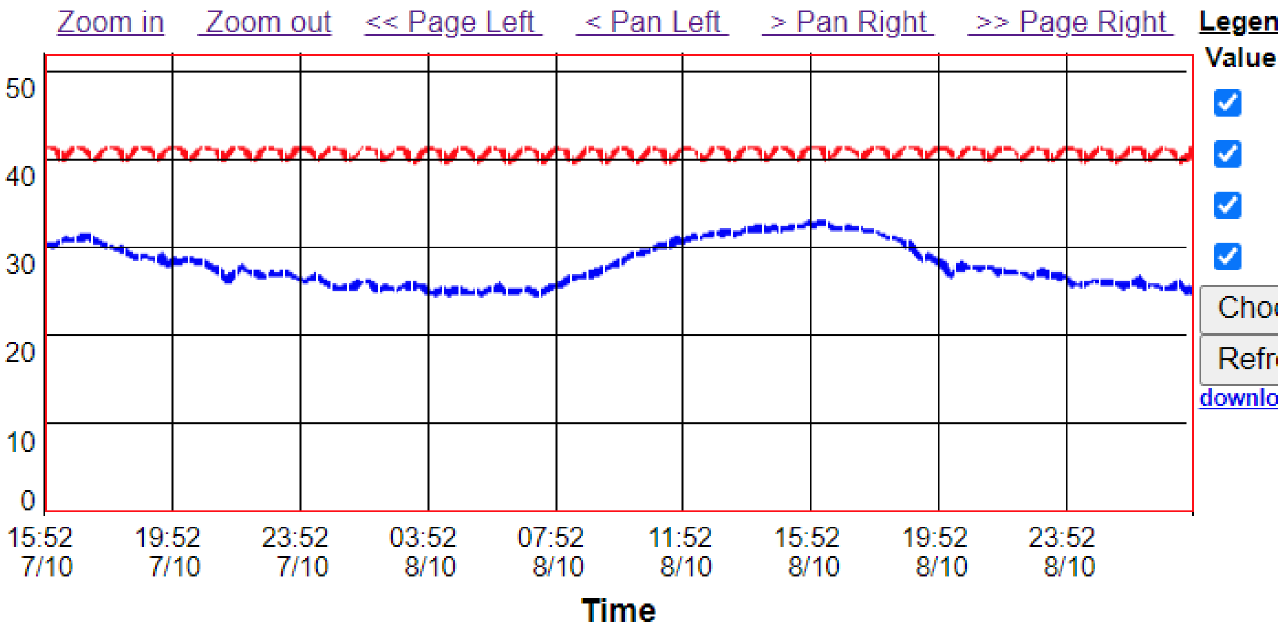
- Electrode service life decreases approximately by half with every 10°C increase of mean temperature. If the LRS has a very good turn-down ratios, it can decrease considerably before the shorting spike becomes a concern. Also, if dust covers and low mineral water are used, the life time is good to start with.
- During a shutdown, the heaters will still need to be provided with auxiliary power to keep the water warm. If this is not done for some reason, the control system must prevent the mill from start-up if the temperature has fallen too low after a shut. If the water was allowed to cool down a lot, it will take several hours to increase the water temperature to the correct level.

A typical control band for the heater thermostats would be 40°C to 43°C, and the electrolyte tuned for a safe start-up torque between 40°C and 50°C. This provides adequate safety margin from the point where boiling of the water becomes serious, which is around 60°C.

Standard heaters used for LRSs are the 1000mm 5kW S5000 Hotrod heaters.

With LRS's that has very good turn-down ratios, another possibility for improving the temperature range is temperature compensation. This basically "scales" the LRS to use only a portion of the run-down when cold, keeping the start-up constant over a wide temperature range. This is the recommended solution, as the "high critical area" problem can also be addressed using the associated control technique, driving the electrodes down with a VSD.

Here is an example of a mill which are following the tight temperature control philosophy



Thu Oct 07 2021 15:52 to Sat Oct 09 2021 03:38

The Red trace is the temperature of the electrolyte, while the blue trace is the ambient temperature

Looking at the example trace, you will notice:

1. Set-point for this mill (in DRC where it can get very hot) is 41degC, which is above expected maximum ambient.
2. Heaters heat the top layer of water where the 500mm temperature probe is located.
3. Every hour the stirrer comes on for 5 minutes, mixing the water, and the measured temperature drops, the heaters switch on again.
4. The net result is that the total tank water temperature remains consistent within 2 or 3 degrees, enabling an accurate start-up torque each time.

The example trace is from an LRS where the Safe Start controls the temperature, but the same can easily be done with a PLC.

6. DETERIORATION OF ELECTRODES

Electrode deterioration occurs as a result of contaminated electrolyte which can be due to dust ingress or bad quality of water used which contain unwanted minerals. The deterioration of electrodes are seen in the TDR, when the TDR dropped, indicating electrode deterioration.

- It is recommended to install Filters on the door louvers to prevent dust from entering into the electrolyte.

  New doors with louvers as well as the recommended filter material as shown below can be obtained from RWW Eng.. Alternatively, the filter frames can be manufactured by mine personnel and be installed on the door panels over the louvers, as per picture below.

Door with the filter housing

Washable filter material

Product name: FWC 200

Filter class: G3-EN779

The filter material may be cut to size and fitted in the filter housing.

7. DEFINITIONS AND ABBREVIATIONS

LRS Liquid Resistance Starter. A variable resistor inserted in series with a wound-rotor motor during starting. The resistance is obtained by passing the current through an electrolyte solution.

Tag Air-gap Torque. Torque exerted on the motor rotor by the magnetic field in the stator.

ESLT Equivalent Shock Load Torque. Allowance that must be added to the Tag (air-gap torque) to allow for mechanical system response and still be within safety margins.

TDR It is the ratio of the maximum resistance measured to the minimum resistance measured

S.C. Sodium Carbonate (Na_2CO_3) also called Soda Ash

8. REFERENCES

1) Hamilton, R.S. & Dr. Wainwright K.A. & Diering R.P. (2006). Lessons learned from recent failures of gear drives on mills in South Africa, SAG conference 2006 Vancouver

2) Specification AAC Specification 581006 “Torque Limits for Grinding Mill Drives

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