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The Siemens 42ft gearless mill drive, still an evolutionary design approach?

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Abstract

This document summarizes the current design criteria and the due diligence approach from Siemens in designing the next size Gearless Mill Drive, i.e. a 42ft mill. It is a dual design approach considering, on the one hand, the experiences Siemens made with Gearless Mill Drive (GMD) installations over the past 40 years and, on the other hand, using computerized design tools calculating the system behavior where experience does not yet exist.

The evolutionary design approach is based on experience of the current installed base, however the computerized design using Finite Element (FE) modeling is contingent upon the representation developed for the real system. Incorrect or insufficient motor models can misdirect the development and potentially lead to a high risk for a structural failure. The gap between the model and the real system is usually closed by prototype testing, however this is not an option for a 42ft Gearless Mill Drive. The ring motor is not self-supported and needs the mill to fix the rotor poles to and it needs the mill foundation to support the stator. Finally you would need a few thousand tons of ore and possibly even an earthquake would be needed to have a realistic test environment representative of a mine site.

Siemens' approach to minimize the risk of an insufficient motor model is to tune the model with parameters measured on a real operating GMD at Goldcorp's Peñasquito mine in Mexico. The quality of the tuned FE-model is demonstrated by a Campbell diagram showing a very good correlation between measured and calculated natural frequencies.

Keywords

Gearless Mill Drive, GMD, 42ft Mill size, Siemens, condition monitoring, finite element analysis, ring motor.

Introduction

As in all other industries, mining projects are forced to deliver an expected profitability over a long period of time. In contradiction to trends in other industries, however, mining projects are facing extraordinary challenges. More and more new mines will be built in remote and challenging areas with high altitudes or extreme environmental conditions. Moreover, new projects are facing lower ore grades compared to projects of the past, requiring ever greater amount of ore processing.

These challenges have always been a strong motivation to gain profitability by increasing the throughput with larger and more efficient and higher available equipment. The demand for grinding mills beyond today's standards of 40ft is just part of the natural market development and will soon challenge the suppliers. Past experiences guided Siemens to establish a new culture in designing bigger and more powerful Gearless Mill Motors for the expected demand for 42ft and 44ft mills.

The evolutionary design methodology is to reuse proven design elements. A detailed risk assessment and root cause analysis is the basis of the Siemens 42ft ring motor design. However, as the first installations of the 40ft GMDs at Cadia and Collahuasi have shown, evolution is not enough. A proven Finite Element (FE) modelling has to give the insight beyond experience.

Simulation can reduce the remaining risk of a new design only if we ensure the computer model portrays a realistic image of the reality. Siemens tuned and evaluated their ring motor FE-Model with the

19.3MW Gearless Mill Drive at the Peñasquito site in Mexico. Up to forty acceleration sensors have been placed inside the motor to measure the impact of two exciters attached at the top and the bottom of the motor housing. These tests provided a detailed frequency response and structural stress analysis of the motor during different situations:

- Stability of the motor construction as built
- Structural stress impact of the magnetic pull to the stator after energizing the drive
- Motor behavior during normal operation with a loaded mill

The result is the design of a Gearless Mill Drive motor for a 42ft Grinding Mill providing up to

35MW of power. Evolution is still the main GMD design philosophy, but realistic and proven computer models help to look beyond experience, where testing is impossible.

Development Strategy

As in the past, with the goal limiting uncertainty, Siemens applied a conservative development strategy. Based on their experience, Siemens defined and applied rules for the development of the 42ft frame size of the GMD. Those are:

- No completely new, unique components or elements should be used
- New components, elements or technologies shall only be applied to the GMD, if successfully in operation in similar applications (New elements)
- All necessary changes in design shall be on the basis of proven design elements, which are already in operation
- All steps of change must be well engineered and verified with powerful and proven design tools
- All engineering and design tools shall be validated by measurements in the field

Uniqueness, new design elements

Siemens has not use new, unique components or elements in the design of the 42ft GMD. All the components and elements have been successfully in operation in GMDs and other Siemens motors for many years. A proven design element is the welded fixation of the laminated iron core in the stator housing of the GMD.

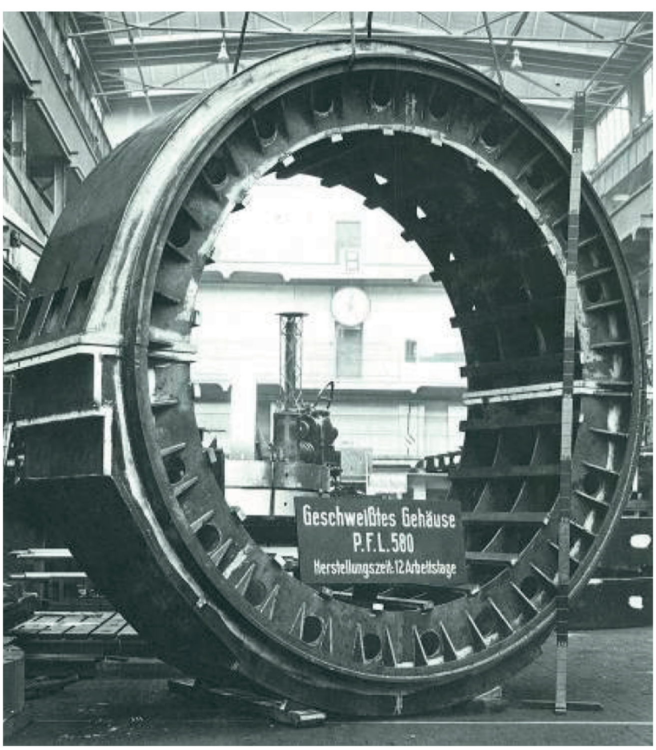

Figure 1: 1955, Siemens Motor with welded fixation of the stator core

The fixation of the laminated iron core by welding it to the stator housing has a proven track record decades long and has been applied to the 42ft GMD Ring motor.

Figure 2: Welded laminated iron core of a Siemens Ring-Motor; view inside the housing

Another proven design element is the cooling system of the ring motor. Siemens distributes the cooling system around the stator and uses axial cooling air flow in closed circuits.

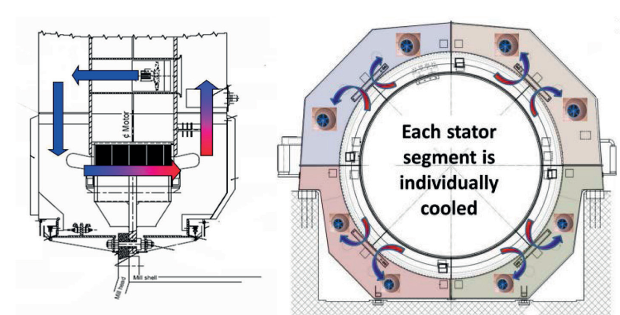

Figure 3 - Cooling scheme of the Siemens ring motor

Each cooling unit consists of two fans and one air-to-water heat exchanger. The fans push the air in a closed circuit through the motor. The air cools the active part of the motor and the heat-exchanger re- cools the air. Several such cooling units are distributed around the motor to provide equal and consistent cooling effect to all parts of the motor. GMDs up to 28,000 kW (37,550 HP) with such cooling systems are successfully in operation for several years so the obvious step is to continue using this cooling concept with the 42ft GMDs as well.

The most successful design element of Siemens GMDs, the VPI-insulation, has also been applied to the 42ft GMDs. Siemens developed VPI-insulation (Vacuum Pressure Impregnation) in the 1960s and registered it under the trademark MICALASTIC®: The first motors with MICALASTIC VPI-insulation were delivered in 1966. In the meantime, more than 10,000 motors with MICALASTIC VPI-insulation have been delivered. All Siemens GMDs are equipped with MCALASTIC VPI-insulation.

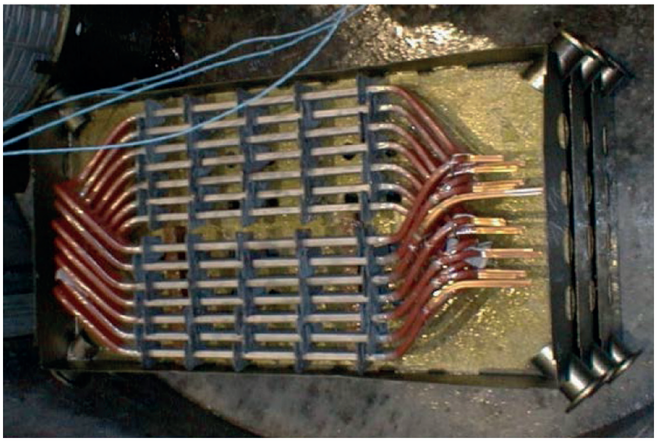

Figure 4: Coils for a GMD during fabrication in the VPI-tank

Many measurements have been performed to prove the quality of MCALASTIC VPI-insulation, especially for high-altitude applications, which are common in the mining industry. In March 2009 Collahuasi's specialists tested Siemens coils with VPI-insulation in their HV-laboratory at 4250 m above sea level.

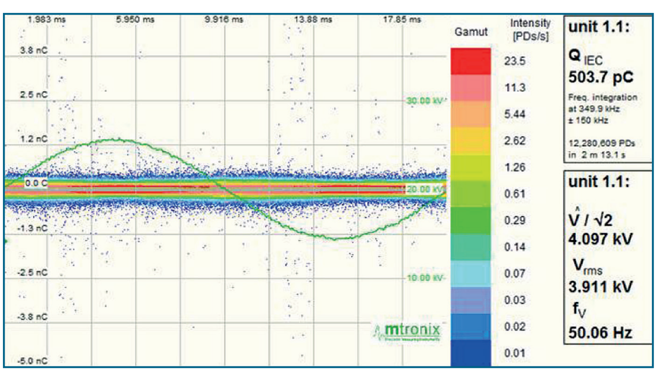

Figure 5: Partial Discharge measurement of a Siemens GMD stator coil at 4250 m a.s.l.

The Collahuasi engineers are the professionals with the most experience in electrical measurements at high altitude. According to their experience the partial discharges of a new winding insulation must be less than 5,000 pC at rated motor voltage. The tested Siemens winding showed only 10% of that maximum value. Therefore, VPI-insulation is the only suitable winding design for a 42ft GMD.

Validation of Engineerig tools

As mentioned the challenge of designing and manufacturing a new and larger ring motor for a Gearless Mill Drive application is that it is beyond experience. Due to cost consideration, building and testing a prototype is not possible. The ring motor is not self-supported and requires the mill to mount the rotor poles and needs the mill foundation to support the stator. In addition, considerations for mill loading and environmental factors such as earthquakes would be required to accurately represent conditions at a typical mine site.

Such a prototype testing is unrealistic and sot we rely on our experience, our calculation and simulation tools. The challenge is that if the model you use is not a realistic and perfect image of the real system behavior, the simulation can mislead your design. The parameters of a ring motor model can't be found in existing literature and thus Siemens focused on identifying realistic parameters by measurement.

Some years ago Siemens performed a comprehensive test series to identify the real values of the Finite Element Model parameters of the ring-motor. The tests were made at the Peñasquito mine site in Mexico at the 38ft 19.3 MW SAG-Mill GMD delivered by Siemens. The aim of the test program was to identify all real natural frequencies in a modal analysis.

Experiment setup

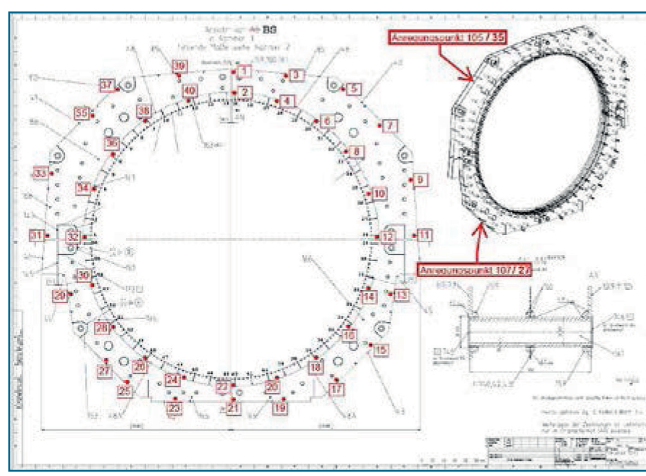

Figure 6: Test equipment; location of the 3D- vibration sensors

Siemens placed 40 acceleration sensors in the motor housing, each measuring the acceleration in three dimensions at the point of installation. Two shakers were attached to the motor housing, one at the top and one at the bottom, to excite vibrations on the motor housing structure. The high inertia of the shaker-machine decoupled the motor housing movements from the exciter.

Figure 7: Vibration exciter attached to the motor housing

With this apparatuses setup we excited the motor housing with frequencies from 2Hz to 20Hz in small steps of 0.1Hz to avoid missing any possible resonances. This procedure was performed for exciting the motor housing in the x- and afterwards in the y-direction in each case at three different operation modes:

- All currents and power off; measuring just the structure
- Stator current off, but excitation on; measuring structure behavior at full magnetic pull
- Motor in operation at rated speed

Measured results

As expected we measured the axial and lateral mode shapes as already known from the FE-Analysis. There were no other mode shapes measured as those calculated before. The axial forces on a grinding mill are too small to excite axial mode shapes, but during seismic events the ring motor might face considerable axial forces. The axial mode shapes have to be known and considered for seismic risk analysis. Notably the lateral mode shapes might get excited by normal operation frequencies.

Figure 8 and Figure 9 show the measured results. The lines connect the position of the sensors. The red line in relation to the blue one gives a quantitative feedback of the mode shape amplitudes with arrows showing the direction of forces.

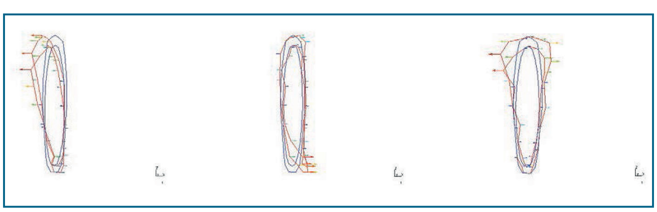

Figure 8: Measured typical axial mode shapes bending and twisting

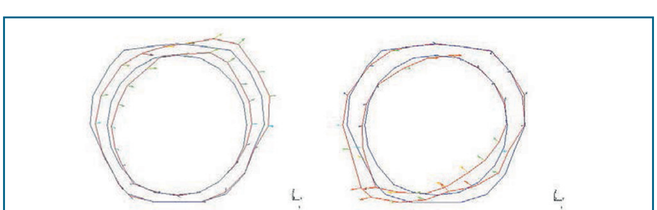

Figure 9: Measured lateral mode shapes, ovalisation

Most interesting was now, how the measured lateral mode shapes comply with the results of our FE-model used at this stage. The Campbell diagram at Figure 10 shows a good correlation between measured and calculated lateral natural frequencies. The measured values are higher than the calculated ones, which tells us that Siemens' calculation is sufficiently conservative and the safety factor between natural and operating frequencies at Siemens' ring motors is more than adequate.

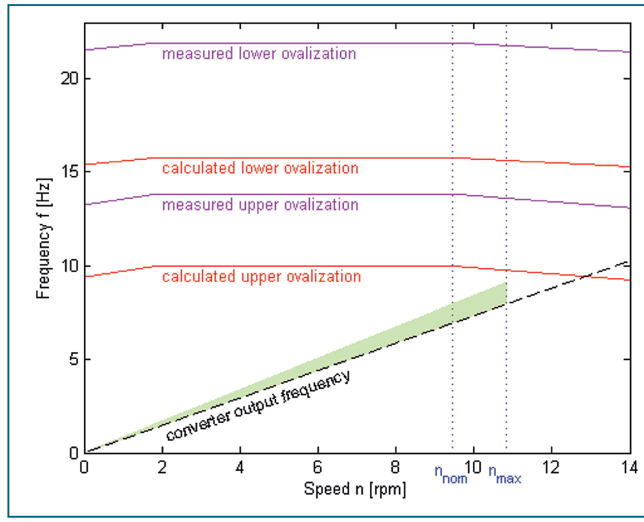

Figure 10: Campbell Diagram; comparing measured and calculated natural stator frequencies

In a second step Siemens attempted to optimize the FE-Model of the ring motor to make it an even better reproduction of the real system. The structure to be remodeled is the stator housing with the stator core. The stator housing consists of steel plates, beams and pipes, elements which can be described precisely with current FE-modeling technology. This means, the difference between reality and the FE- model is not due to the housing rather to the stator core behavior. Up until now the stator core was modeled by using a closed ring of volume elements with a low isotropic elastic modulus.

Analyzing the measurements we discovered that the low elastic modulus of the stator core is correct for the axial direction only, but for the y- and z-directions (orthogonal to the mill axes) the Young's moduli are about six times higher than supposed in the current FE-model. The tests showed the stator core has to be considered with an anisotropic Young's modulus.

Next we had a closer look at the anchoring system of the motor was performed. So far the stator anchoring was modeled by one beam element per foot bolt. The FE-model of these beam elements corresponded with the pressure cones and the clamping length of the foot bolts. Based on the measurements made, a more detailed FE-model of the anchor bolts, foot bolts, sole plates and the surrounding concrete showed a more rigid behavior than expected. The rigid beam elements for the foot bolts were exchanged in the FE-model with spring elements using a stiffness based on measured parameters.

All in all the updated FE-model of the ring motor now shows the same behavior as the measurements. The Campbell diagram of Figure 11 compares the natural frequencies of modeled and measured stator.

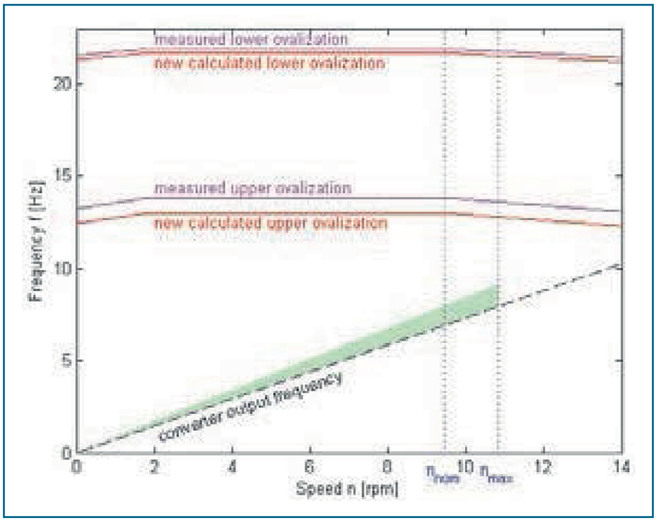

Figure 11: Campbell diagram comparing the updated FE-model with measured natural frequencies

Risk mitigation

Failure Mode Effects and Criticality Analysis

To develop the 42ft GMD, Siemens performed a Failure Mode, Effects and Criticality Analysis (FMECA) of GMDs with respect to reliability and availability of GMDs on the basis of historical issues. The methodology of the FMECA summarizes the following steps:

- Which issues occurred?
- Which are the failure modes?
- What is the effect of the failure mode?
- Which risks exist?
- How critical is that effect / risk?
- What can be the consequences?
- What actions must be taken to avoid that risk?
- Which are the lessons learned?

The failures that occurred in the past have been traced and discussed in many papers and won't be discussed further here. More important is the fact that the results of the Failure Mode, Effects and Criticality Analysis are considered in all Siemens GMD deliveries so far and the lessons have been applied to the development of the 42ft GMD. The proven track records of high availability of the Siemens motors delivered in the past decade (Figure 12) proves these concepts are working.

Condition Monitoring

Having a risk-minimizing design concept in place is important to avoid any unforeseen issues at the startup of the GMD system. Ensuring in a good condition of the motor during operation is a methodology of preventive maintenance. Today's condition monitoring systems contribute a lot to ensure the expected high availability during the life time of the motor. A number of sensors permanently measure electrical and mechanical parameters such as the air gap, vibration and temperatures to name just a few. Vibration sensors are typically located on the sole plates and at dedicated points of the stator and rotor poles. Measuring the temperatures of windings and cooling media as well as data acquisition of any electrical parameters are considered state-of-the-art.

In this context the so-called finger print concept is very successful at comparing the actual condition of the motor with measurements at an early stage of operation or with the expected values of the design modeling. Slight deviations in characteristic parameters such as vibration frequencies or amplitudes might give an early indication of a looming failure. The change of system behavior will be analyzed by experts and can be cleared during routine preventive maintenance actions prior to a major shut down.

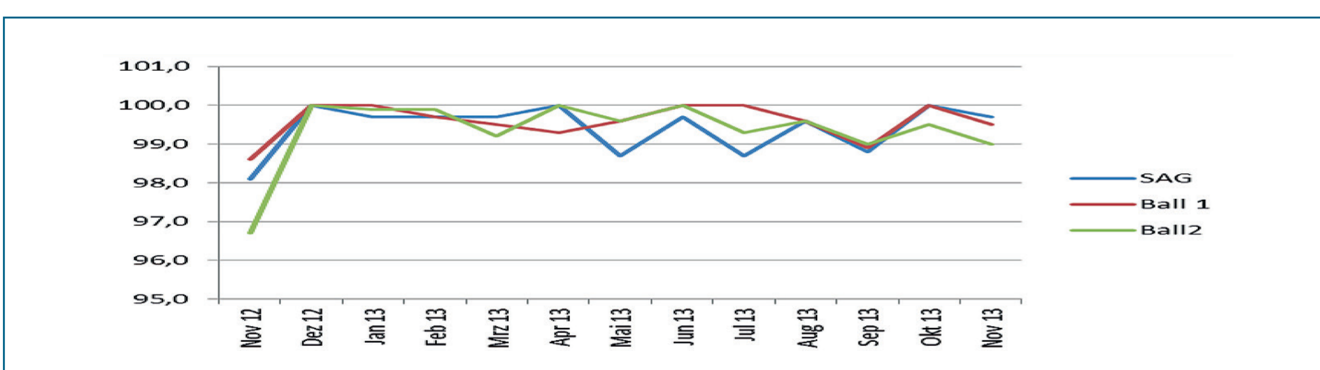

Figure 12: Availability record of the Siemens GMDs at Antapaccay / Peru comprising corrective and scheduled preventive downtimes

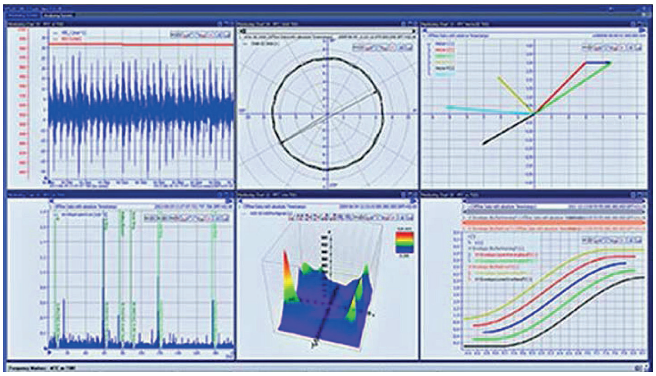

Figure 13: Condition Monitoring; Diagnostic tools support to detect looming failures

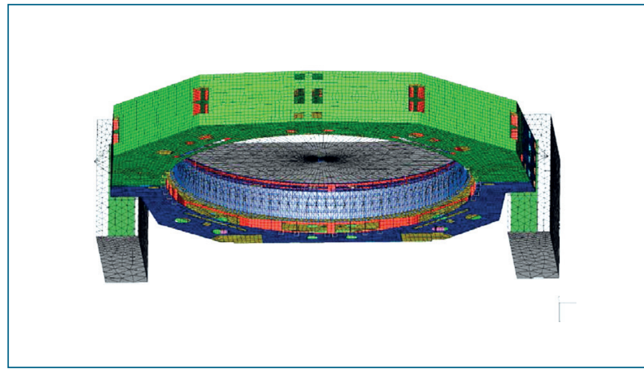

Figure 15: Finite Element Model of the Siemens 42ft GMD Ring-motor

Results of the development

The Siemens 42ft GMD Ring motor is completely designed and engineered. The motor structure is available for fabrication in 3D CAD Model of NX-software.

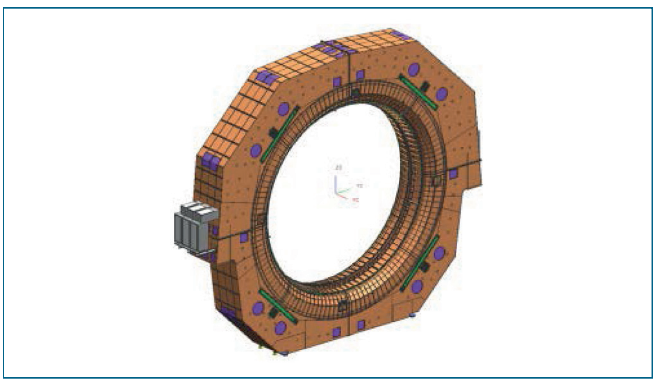

Figure 14: 3D CAD Model of the Siemens 42ft ring motor

With the FE-model of the 42ft GMD, Siemens investigated the behavior in all possible load cases and realized a seismic verification according to UBC 97 for seismic zone 4. Stresses in all parts and deformations of the structure were part of the investigation.

Siemens discussed the interface of the mill and motor with mill suppliers and integrated the 42ft GMD Ring motor and the 42ft SAG-mill into one unit (Figure 16).

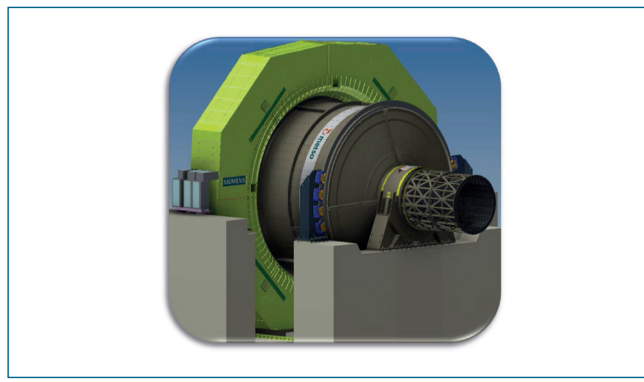

Figure 16: Computer model of a 42ft SAG-Mill with a Siemens GMD

The 42ft GMD is designed to provide the following rated power, depending on site elevation:

- 35,000kW at 1,000m a.s.l.; corresponding to 47,000HP at 3,300ft a.s.l.
- 31,000kW at 4,000m a.s.l.; corresponding to 41,500HP at 13,100ft a.s.l.
- 29,000kW at 5,000m a.s.l.; corresponds to 39,000HP at 16,400ft a.s.l.

Conclusions

The design of the Siemens 42ft Gearless Mill Drive is based on a risk-eliminating development strategy. Proven and reliable design elements and components are implemented again. A FMECA quality procedure ensured that results of root cause analyses are incorporated in the new system. The risk of a potential insufficient FE-model of the ring motor has been removed by tuning the model until the simulated stress tests have been congruent with the measured modal analysis of an operating GMD.

References

Combes, M., Dirscherl, C., & Rösch T., (2014). Increasing availability through advanced Gearless Drive Technology. CMP Conference, Ottawa.

Kuemmlee, Horst & Meinke.Peter (2001). A mechatronic solution design and experience with large Gearless Mill Drives. SAG 2001 Conference, Vancouver.

Meimaris, C., Lai, B., Price, B.F., & Manchanda,. S. (2006). How Big Is Big? Revisited. Vancouver: SAG 2006 Conference, Vancouver.

Meimaris, C., Lai, B., & Cox, L., (2001). Remedial Design of the World's Largest SAG Mill Gearless Drive, SAG 2001 Conference, Vancouver.

Tischler, K. & Petereit, P., (2012). Design and dynamic behavior of large Ring Motors for grinding mills, SMMH 2012 Conference, South Africa.

Tischler, K. & Kennedy, T. (2011). Availability and Reliability of Siemens' Gearless Drives. SAG 2011 Conference, Vancouver.

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