Extending STM's Large Vertical Stirred Mill Portfolio to 12.5 MW

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Abstract

Declining ore grades, complex ore bodies, waste-management solutions and global net-zero initiatives all lead to a clear trend for high tonnage and energy-efficient material processing. Energy-efficient grinding in milling circuits is a major contributor to achieving such targets.

It stands to reason that milling efficiency is improved with the use of large-sized mills as opposed to a series of smaller mills performing the same grinding duty. Comparatively, the reduced footprint required for larger mills leads to reductions in structural concrete, site construction works, installation time, auxiliary equipment, maintenance efforts, and control complexity.

Swiss Tower Mills Minerals AG (STM) offers a range of large, vertical stirred mills (VRM and VPM technologies) with bottom feed, hanging shaft assembly, and open-to-air discharge, which promote less static and dynamic loads that are easily and simply addressed with common structural and mechanical designs. Together with variable-speed drive technology and multi-drive drive systems, STM has been able to design the largest stirred mill on the market, which features a 75,000 litre capacity and 12500 kW installed power. This paper provides an outlook on the development of large VRM and VPM technology mills and explains in detail why the STM technology is not size-limited.

Keywords

Stirred milling, large mills, footprint, energy-efficient grinding

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Introduction

Demand for raw materials and metals is increasing exponentially, stimulating the growth of mining and extraction volume. Increased production as well as improvements in mineral processing technologies, which help extend the life of operating mines, results in declining ore grades. Processing lower ore grades usually means higher plant throughputs and higher energy consumption. Calvo et al. (2016), analyzing only copper mines, report that the average ore grade has decreased by 25% in just ten years, while total energy consumption has increased at a higher rate than production—46% and 30%, respectively.

Being a part of one of the most energy-intensive industries, mining companies are under pressure from society and governments, looking for opportunities to reduce their carbon footprint. Many large mining operators have accepted a decarbonization challenge and introduced a number of initiatives to reach net-zero emissions by 2050. Considering that comminution accounts for 56% of the mining sector's total energy use, or 3% of the world's generated electric power use, there is a strong demand for energy-efficient grinding technologies.

When designing a greenfield concentrator plant, project economics usually dictates maximum tonnage using a single-line comminution circuit incorporating the largest available equipment. Putland (2006) observed that the need for multiple comminution trains is rarely the most economical option if a single-train alternative is available. Quite often a maximum single-train capacity dictates the selection of plant throughput.

Replacing a few smaller mills with a single large unit helps reduce capital investments and operating costs. Shorter engineering time, small footprints, reduced volume of concrete and construction works, faster and cheaper shipping, quicker installation, lower quantity of auxiliary equipment, easier maintenance and process control, and faster return on investment, all contribute to solutions based on using large mills.

These factors have been major contributors to the use of larger scale semi-autogenous grinding (SAG) and ball mill grinding and SAG mill, ball mill, and crusher circuits in the industry, with the design changing little, but the size of the individual pieces of equipment increasing significantly, with the lowering of head grades, and the push for greater economies of scale (Riezinger et al., 2001). Today 38-foot and 40-foot mills with installed power in excess of 20 megawatts (MW) are in operation, and operators continually look for larger and larger equipment to install.

The large-scale machinery trend has been delayed in the stirred mill market space despite this technology becoming a commonplace solution for secondary, regrind, and fine grinding applications.

A number of technical issues limited the design of a large, stirred mill until the VRM and VPM technology was introduced in 2012. Swiss Tower Mills Minerals AG (STM) has become the market leader in large, stirred mills, having supplied many 5000 and 6500 kilowatt (kW) units globally.

Unlike similar equipment from other suppliers, the VRM and VPM technology can be expanded and allows for very large mills and installed power. The hanging vertical-shaft arrangement allows for straightforward mechanical design principles. The main forces run in a vertical direction and are absorbed and handled by the gearbox and support frame, which in turn translates the forces into the supporting foundation. The shaft end is un-journaled and is loosely located within a guide cone at the bottom of the mill shell. The mill shell, in which the grinding chamber is found, also hangs and encapsulates the shaft, taking no forces from the mill shaft and the grinding that is taking place (Figure 1).

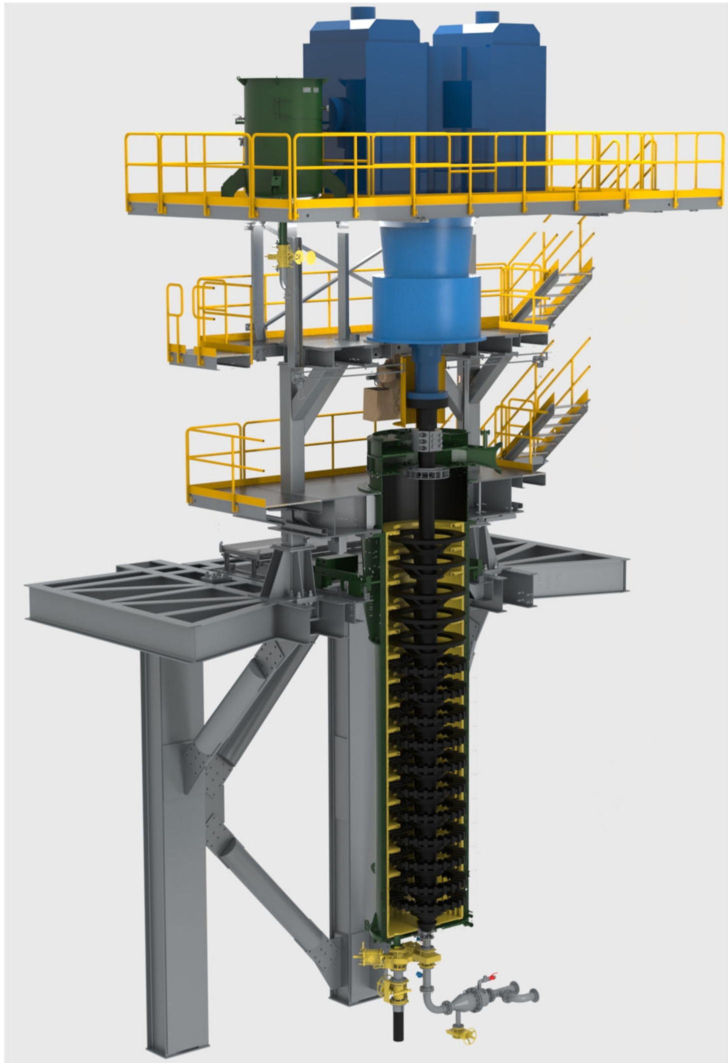

Figure 1—Typical VRM mill cross section

Following on from the manufacture and delivery of many 50,000 litre (L) mills paired with 5000 and 6500 kW drivetrains, as well as seeing a growing demand from customers, STM has designed a 75,000 L mill. The result is the largest stirred mill (12500 kW), which has been recently introduced to the market.

Through the basic engineering phase, solutions for particular challenges had to be developed, challenges such as: scaling up grinding conditions from small to large mills, predicting the large mill power draw, finding an optimal solution for a multi-megawatt drive, and analyzing the structural integrity of the system and some others.

The VRM 75000 is an evolution of the VRM 50000. The mill frame is similar, only with a bigger inner chamber diameter. The mill shell, which is fixed to the mill frame in a hanging design, has the same height-to-diameter ratio, with the mill gross volume increased to 75 cubic metres (m^3). The mills multidrive system consists of two motors connected to a parallel shaft gearbox via the torque limiting couplings. If the maximum available installed power is not required, the mill can be equipped with a single drive unit similar to smaller mills. As applied on all STM mills, the VRM 75000 drive is paired with a variable-speed drive (VSD) for mill speed and torque control.

Principles of STM Technology

Introduced to the market in 2012 by STM, the VRM and VPM technology is a globally recognized solution for the mineral processing industry. The technology has proven its economic benefits over alternative stirred milling solutions. Designed for energy-efficient fine/ultrafine/regrind/tertiary (VRM) and primary/secondary (VPM) grinding, the technology provides significant advantages.

POWER SAVINGS AND INTELLIGENT USE OF GRAVITY

Grinding in STM mills is achieved by attrition, during the interaction between feed particles and grinding media. The feed slurry is pumped from the bottom through the stirred bed of media, which typically occupies up to 60% of the mill volume. Gravity prevents overflow of media from the mill and ensures it is evenly distributed across the grinding chambers. Rotating grinding rotors apply energy only radially; therefore, no power is lost in lifting the mill media charge (Figure 2).

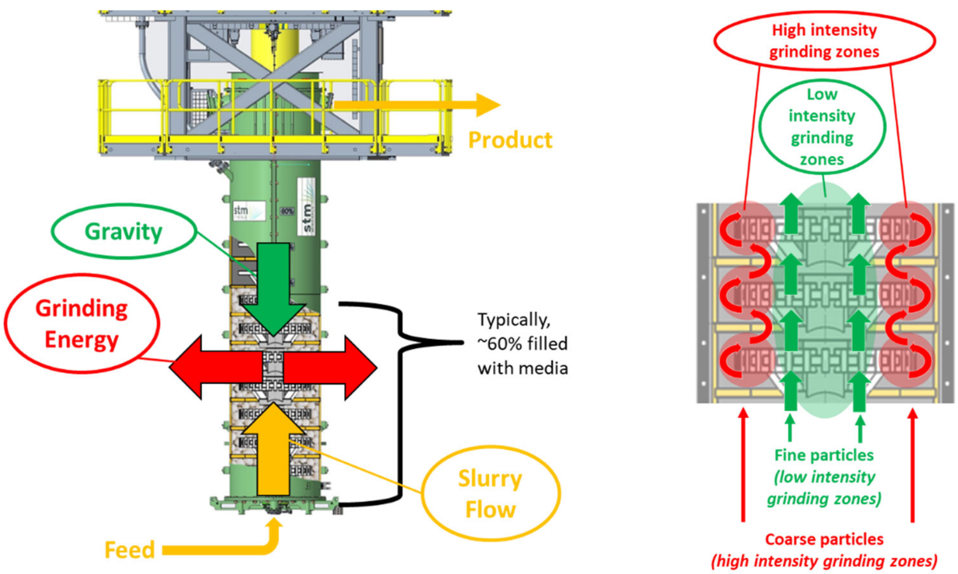

Figure 2—Principle of STM mill operation

MULTI-COMPARTMENT DESIGN

Feed and discharge are at the opposite ends of the grinding chamber. Fixed stator rings on the mill shell and rotating grinding rotors create separate compartments around each rotor and force the slurry to move through the mill similar to a plug flow reactor, eliminating short-circuiting or dead zones.

SELECTIVE GRINDING

Due to centrifugal force created by the rotors, coarser particles and grinding media are pushed out into the high intensity grinding zones on the periphery of the grinding chamber, while finer particles travel upwards closer to the mill shaft reducing the grinding effect (Figure 2). This design feature prevents overgrinding and makes sure the energy is applied mainly to coarser particles, helping maximize energy efficiency.

OPEN CIRCUIT FLOWSHEET

The slurry flow path together with the selective grinding mechanism results in a steep product particle-size distribution where the target grind size is achieved in one pass through the mill with no recirculation required (Figure 3).

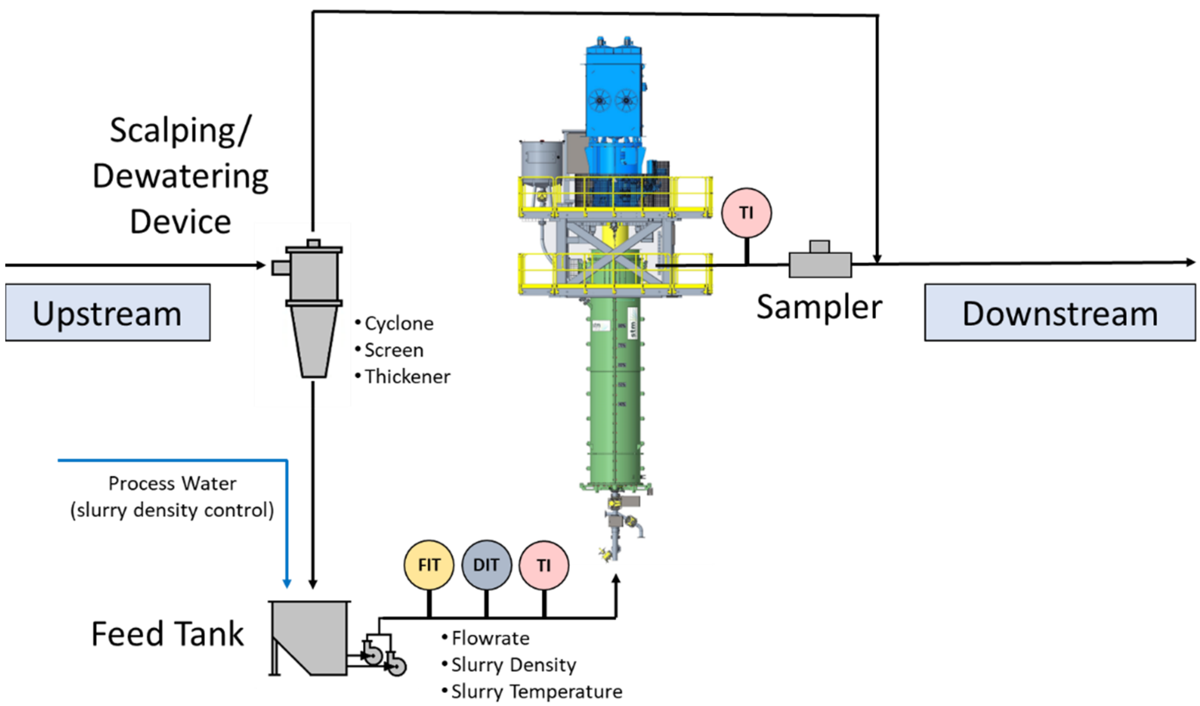

Figure 3—Typical STM circuit

FLEXIBLE MILLING PROCESS CONTROL

The mills are equipped with VSDs to enable control of the applied specific grinding energy and thus management of the product size, compensating for possible fluctuations of the feed characteristics. This feature provides consistent and uniform product which feeds the downstream processes, maximizing downstream recovery.

THE BIGGEST STIRRED MILLS IN THE WORLD

STM offers mills in the range of 75 to 12500 kW, from small pilot mills to the world's largest stirred mills. Application range varies from ultra-fine and fine to conventional grinding with feed size up to 6 mm. Smaller mills (7 and 30 kW) are available for testing and testwork purposes.

SIMPLE MAINTENANCE

STM mills have been specifically designed for simple, fast, and safe maintenance. The mill shaft assembly and shell liners are lowered and lifted using the integrated electrical maintenance chain blocks.

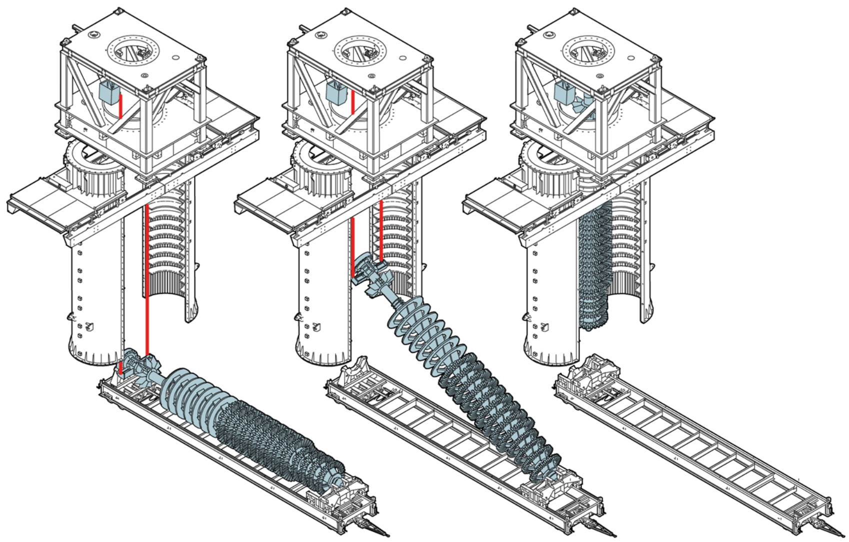

Figure 4—Installation and removal of the STM mill shaft assembly

Scalability

STM uses advanced testing methods ensuring 1:1 upscaling accuracy from lab testing to production mill. The same grinding mechanism, media size and type, and slurry density are used in the test- and production-size mills; therefore, no additional special scaling factor is required. This allows STM to increase the mill size without jeopardizing the high energy-efficiency, and continues producing the unique, steep mill product particle-size distribution curve providing the best possible downstream process benefits.

The specific grinding energy 1:1 scalability has been proven by a few surveys at operating concentrator plants. A few examples are provided below.

In February 2015, First Quantum Minerals commissioned a new fine-grinding circuit to boost the metallurgical performance of its Kevitsa copper–nickel operation in Finland (Lehto at al., 2016). The heart of this circuit is a 700 kW 4000 L VRM mill (supplied by Outotec as HIG700) producing a 20 micron (µm) regrind product to enhance particle liberation for improved downstream flotation performance. As Lehto et al. (2016) report, a sample collected from the operating regrind mill feed was tested using 5 L and 25 L test VRM mills. The results (SGE vs. P_{80}) matched very well with performance of the production mill (Figure 5).

Santa Elena Mine, owned by First Majestic Silver Corp. (FMSC), is 168 Km Northwest of Hermosillo, Sonora State, Mexico, and commenced operation in 2011 (Mezquita et al., 2022). The existing processing plant (commissioned in 2014) was originally designed as a dynamic leaching process with a nameplate capacity of 3,000 tonnes per day for a grind size of 80% passing (P_{80}) 100 µm. In early 2018, FMSC and its metallurgical team identified the opportunity to improve gold and silver recoveries by modifying comminution processes that increase the exposure of valuable minerals. The design criteria for the regrind mill product was defined as P_{80} 50 µm. The recovery increase is associated with processing of a finer feed through the leaching circuit. The implementation of the regrind circuit has demonstrated considerable benefits after a VRM 9000F (HIG1600/9000F) was successfully commissioned at Santa Elena silver mine in 2019 as the secondary grinding mill. Mezquita et al. (2022) showed the relationship between applied specific grinding energy and resulting product fineness during the actual operation was found to be in line with the signature plots from the pilot testwork (Figure 6).

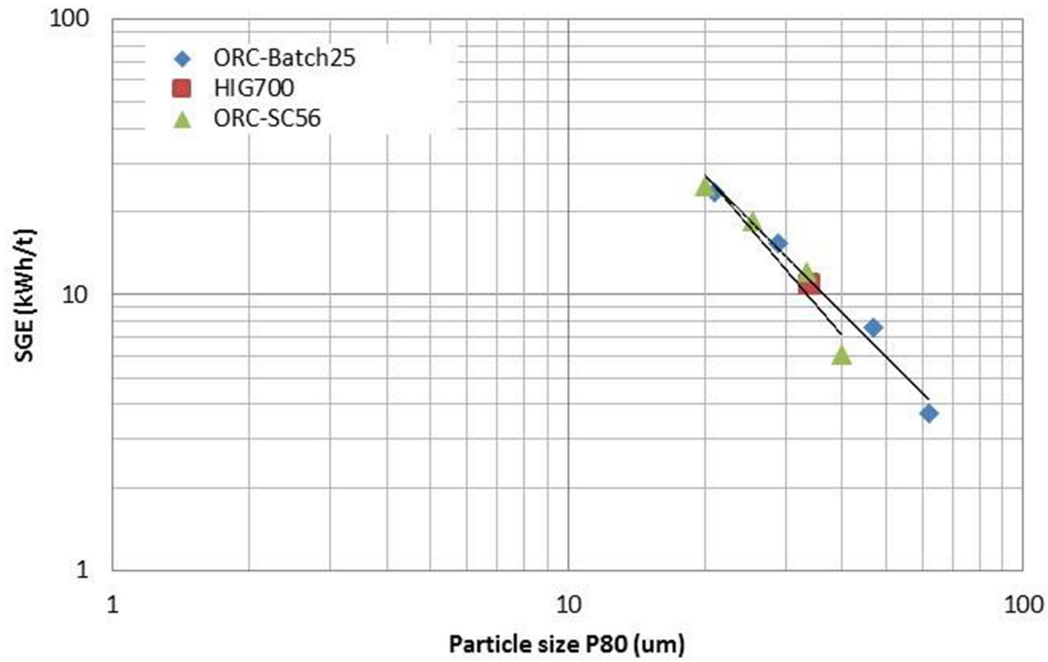

Figure 5—Kevitsa scaleup results—VRM 5 (Test ORC-SC56), VRM 25 (Test ORC-Batch 25) and VRM 4000 (HIG700)

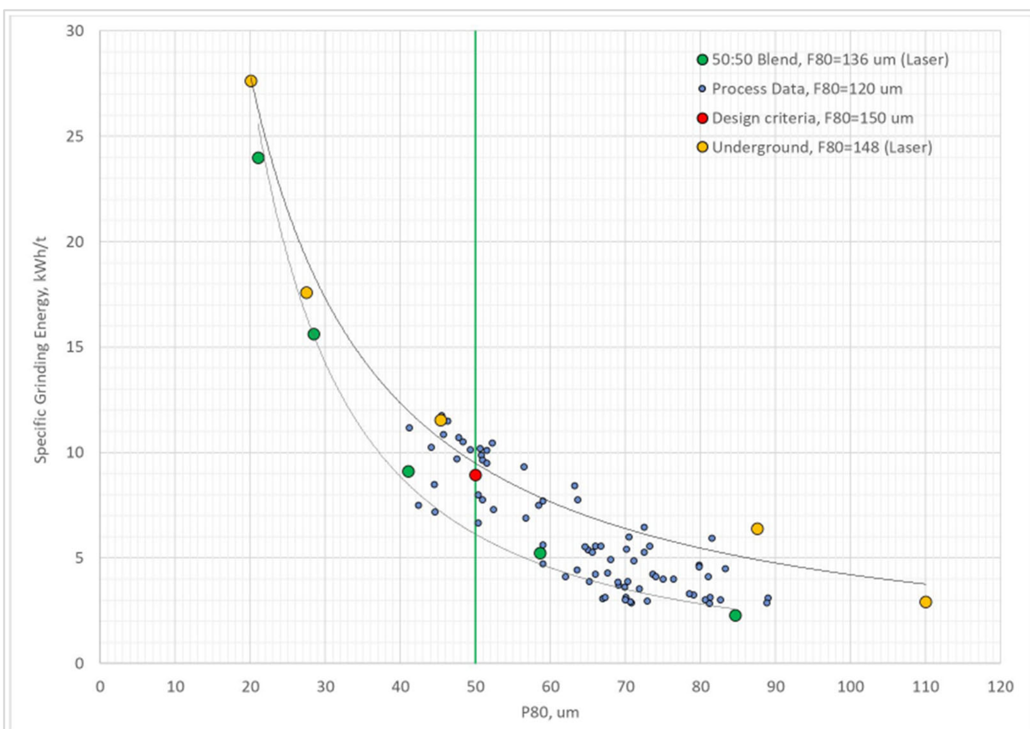

Figure 6—Santa Elena operating process data vs. signature plots

The AngloGold Ashanti Sunrise Dam Gold Recovery Enhancement Project was an upgrade project to the existing process plant to increase gold recovery (Paz et al., 2021). The project required the existing screened cyclone overflow to be redirected into a new flotation and ultra-fine grinding circuit, producing concentrate up to a rate of 400,000 tonnes per annum (t/a). A HIG3500/23000 (VRM 23000) was selected as the ultrafine grinding mill for the project. At this time this mill is the world's largest stirred mill supplied into a pyrite concentrate ultrafine grinding duty.

The mill is in open circuit, with all concentrate reporting to the mill for a single pass. A grind of P_{80} 9–12 µm is achieved, delivering additional recovery in the 6% to 8% range (Paz et al., 2021).

In 2020 an on-site scale-up pilot test was conducted to study the effect of residence time and operational density on the energy efficiency. A full-scale mill survey was conducted where feed sample was collected for further testwork using 5 L lab mill. Paz et al. (2021) showed that residence time of 2 and 3 mins in the 5 L unit did not affect the energy efficiency significantly compared to the full scale (Figure 7) given a 1:1 scale-up factor.

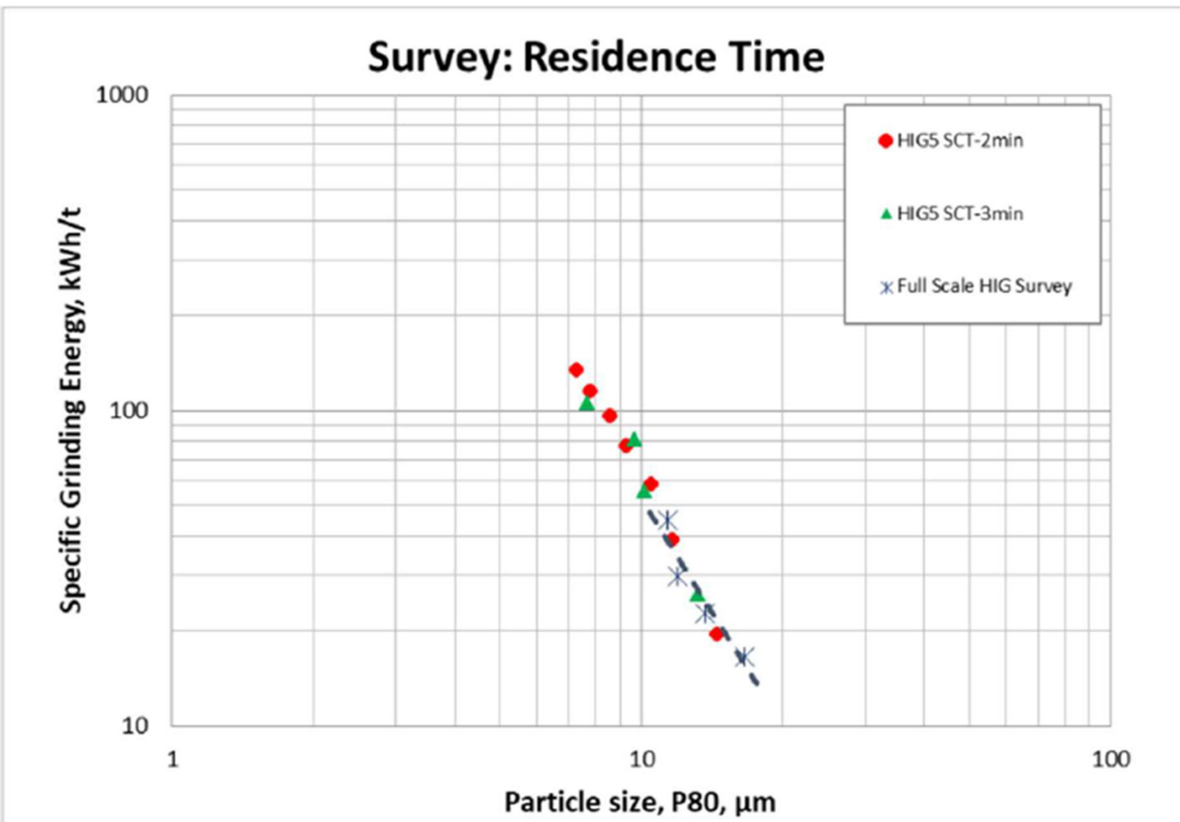

Figure 7—Sunrise Dam scale-up testwork: VRM 5 (Tests HIG5 SCT-2 min and HIG5 SCT-3 min) and VRM 23000 (Full Scale HIG Survey)

STM's testing methodology ensures 1:1 up-scaling accuracy from the 5 L lab-testing unit to the world's largest production mills, in a range of applications spanning typical regrind duties to ultrafine grinding. These results gave STM the confidence to develop a 75,000 L unit.

Mechanical Design

STM mills are designed using various numerical simulations tools—for example, finite element analysis (FEA), computational fluid dynamics (CFD) simulations, and the discrete element method (DEM). The structural integrity of the complete mill is assessed by stress values obtained from finite element simulations. In these simulations various load cases are considered, such as gravity, rotor unbalance, wind loads, and seismic loads. The load cases have been applied and experimentally validated on the smaller mills. Furthermore, the FEA is applied to identify the Eigenmodes of the complete structure, including the grinding media. An example of an Eigenmode is depicted in Figure 8. By FEA analysis, during the design phase it is possible to ensure that no Eigenfrequencies of the system are within the operational range of the mill. The modal analysis is complemented by a harmonic response analysis. For this analysis the rotating masses are used to excite the system. The excitation forces are based on models that have been validated by mills already in operation, such as VRM 23000 and VRM 35000. The harmonic response analysis can be done again to estimate the vibration velocities on the operating mill after commissioning.

Validating the structural simulations is done either by acceleration measurements on various locations in the mill as well as by strain gauge measurement on the mill frame and mill shaft. Both measurement methods are used to verify the load assumptions and to prove that there are no harmful vibrations in the mill, especially the mill shaft. An example of an applied measurement set-up is shown in Figure 9.

The mill power draw is analyzed by means of DEM. Therefore, a section model of a single milling disc is set up considering the liner geometry as boundary condition. The dimensions are scaled up from the existing smaller mills. The media is represented by spherical particles with the actual media size and material parameters. The DEM model is shown in Figure 10.

The simulations give, on the one hand, the velocity of the induvial beads, and on the other hand the power draw of the milling disc. This simulation has been performed for various mill sizes and the power draw can be linearly scaled up based on the mill disc diameter (Figure 11).

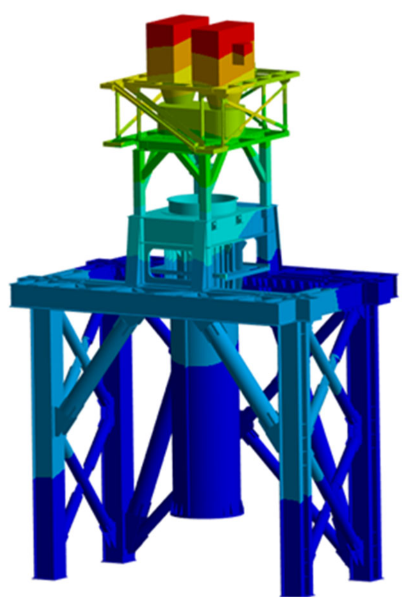

Figure 8—Deformation plot of a modal analysis of the complete mill

Figure 9—Left: Vibration sensors on the mill frame feet; Right: strain gauge set-up on the mill shaft

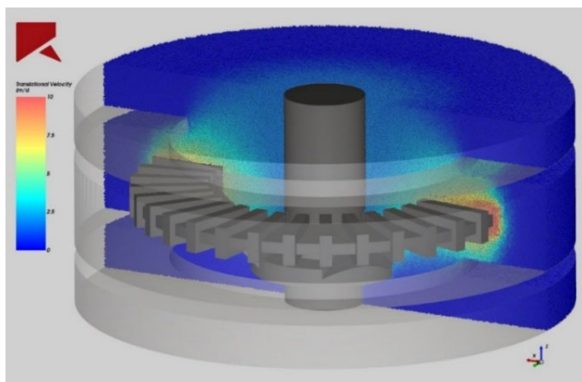

Figure 10—DEM model of a single milling disc (the scale shows the translational velocity of the beads)

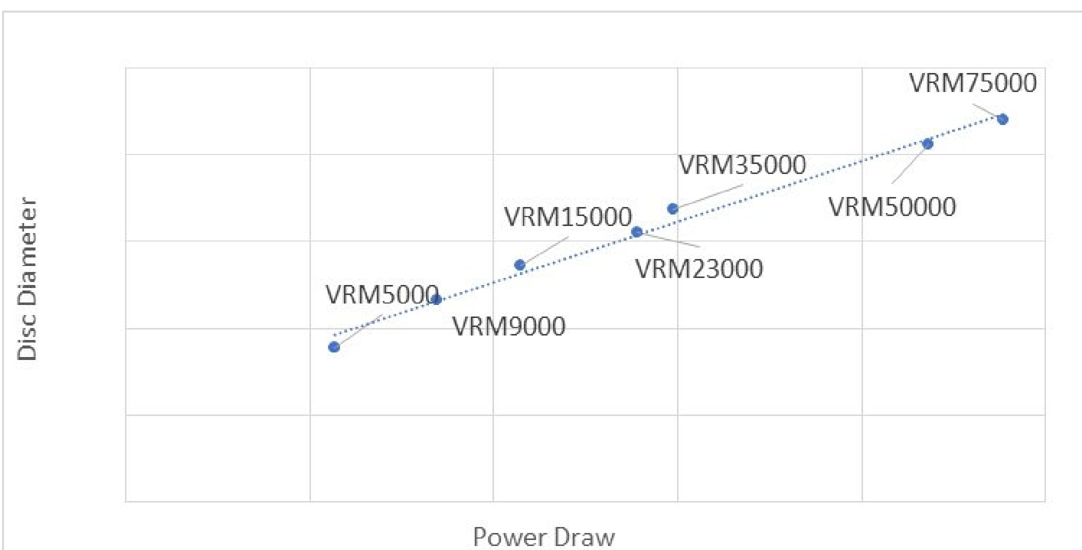

Figure 11—Computed (DEM) power draw vs. disc diameter

The CFD method is applied to improve the separation efficiency of the media classifier. The classifier is below the mill outlet and has the function to propel the media to the mill wall to avoid them being flushed out of the mill. The size and the design of the classifier is optimized by CFD simulations. By this, the efficiency of the retention of media could be significantly increased. In addition, the impeller power draw can be computed. The fluid velocity due to the impeller rotation is shown in Figure 12. The velocity lines show that the media is accelerated to the mill shell before entering the section of the mill outlet.

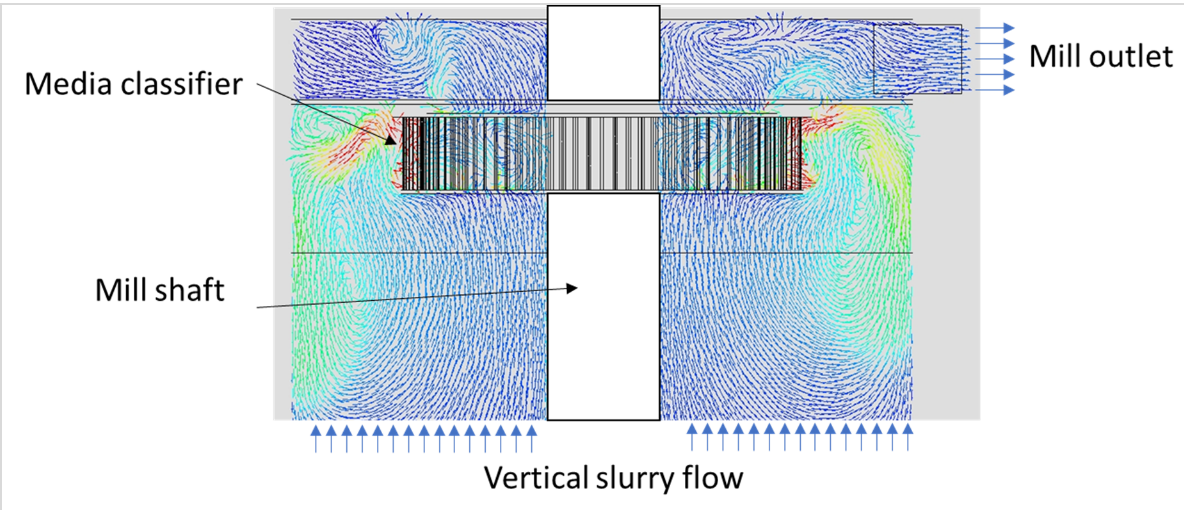

Figure 12—Velocity plot of the CFD simulation of the classifier

Extended research projects have been started to combine the DEM and CFD simulations. These projects include the experimental model validation, including full-scale measurements on the research mills.

Mill Drive Design

MULTIDRIVE SYSTEM

Modern-day drive systems are able to deliver constant torque and power through a defined speed range with precision. Several different control modes for mill drives area available, such as scalar, vector, or other direct-torque controls. Due to specific application for the vertical stirred mills, the operation of the motor in overspeed is sometimes required which can be achieved by using VSD.

Due to several technical limitations and design challenges faced by motor producers, a multidrive system was selected for large vertical stirred mills where the total power can be easily expanded to 12.5 MW or more.

On the VRM 75000 two flange-type electrical motors are connected to a parallel shaft gearbox. The connection between the motors and gearbox is done via torque-limiting couplings (Figure 13). In the case of parallel-shaft gearboxes with a double-drive system, the motors can cause considerable mechanical stress. For smooth and safe operation, it is important that critical situations are avoided as far as possible. Therefore, in addition to torque-limiting couplings, a fast and precise load sharing between the two motors is required to avoid any additional stress on the gearbox. These requirements can be fulfilled with modern multidrive technology.

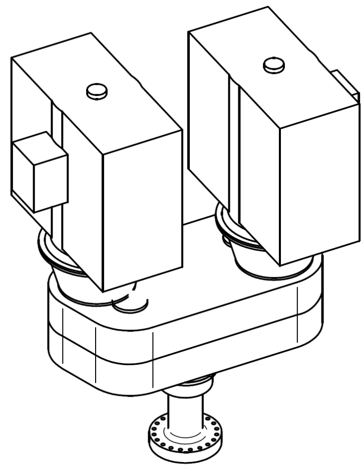

Figure 13—Dual drive system with VRM 75000 gearbox

The multidrive system is designed as a “Master/Follower” application, where torque control of both motors is very important. The vector control in the drive will prevent rough starting, torque peaks, and load variances between the two motors. To minimize communication delay, on the hardware side the two main drives are coupled to each other via a high-speed communication link—the follower inverter unit follows the speed and torque reference of the master unit in real time. As a result, the torque difference between the two motors is typically below 1% of the rated torque.

GEARBOX WITH LUBRICATION UNIT

Due to the design of the vertical stirred mill, a gearbox with two input shafts is required, with an overall gearbox ratio of 8.85 (Figure 14).

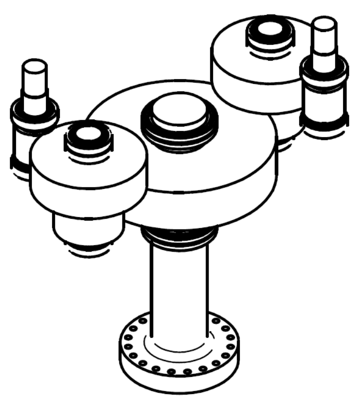

Figure 14—Basic parallel shaft gearbox sketch

The gearboxes for large mill sizes are typically lubricated using spray lubrication. The unit often has spray lubrication provided from an external lubrication unit through the use of nozzles, with oil circulating at a pressure up to 1.5 bar. The lubrication system is free-standing and connected to the gearbox through oil supply and oil return pipes.

Both systems—gearbox and lubrication unit—are equipped with all necessary instrumentation and sensors needed to control and supervise the stable operation of the system.

Evolution of Mill Design

As discussed above, the design of VRM 75000 has been scaled up from the existing VRM 50000, ensuring a smooth evolution of a well-proven concept. Nevertheless, a number of important upgrades have been added to the new mill.

The main focus was on improving the ease of maintenance and reduction of downtime. One of the biggest changes was made in the mill frame design. The frame consists of two parts for ease of transportation. By varying the height ratios of the upper and lower parts of the mill frame, the shell shift unit design was simplified, which would make it easier to open the mill shell during maintenance, as there is now more space for changing wear parts (Figure 15).

The total number of parts at the mill discharge end was reduced, to simplify preparation for mill shaft removal aiming at reducing maintenance downtime.

The grinding media hopper was moved closer to the mill shell, decreasing the dosing-hose length for smoother operation. Simpler mill frame design, as well as more compact location of the media hopper, allowed a significant reduction of the platform's size.

A few modifications were made in the shaft maintenance trailer and shaft lifting tool design for faster and easier assembly and disassembly. The operators now can control the trailer from a greater distance, improving work safety as well.

The trailer can also be used now during replacement of the shell liners (Figure 16). Half of the mill shell can be placed on the trailer with the help of an intermediate console, and it is possible to replace the liner more easily. The shell halves are removed by an overhead or mobile crane as it was in the previous design. Alternatively, the liner segments can still be replaced in situ, with the mill shell opened.

The VRM 75000 provided a basis for the VPM 50 mill design, which in fact is a shorter version of the VRM 75000, suitable for coarse grinding applications with feed material size up to 6 mm (F80 3 mm).

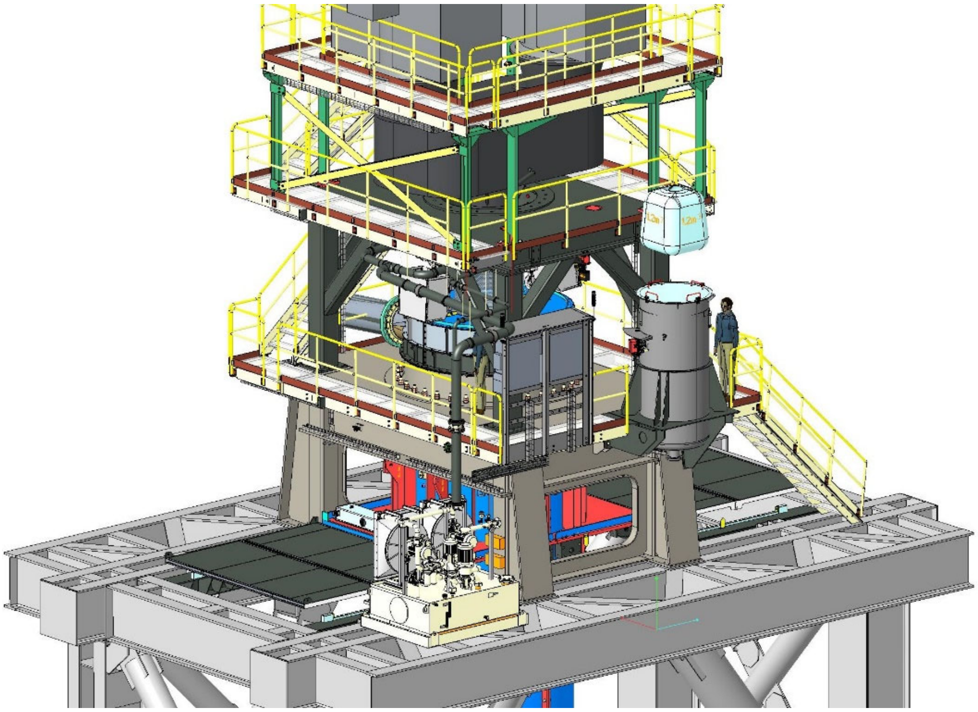

Figure 15—VRM 75000 mill frame design

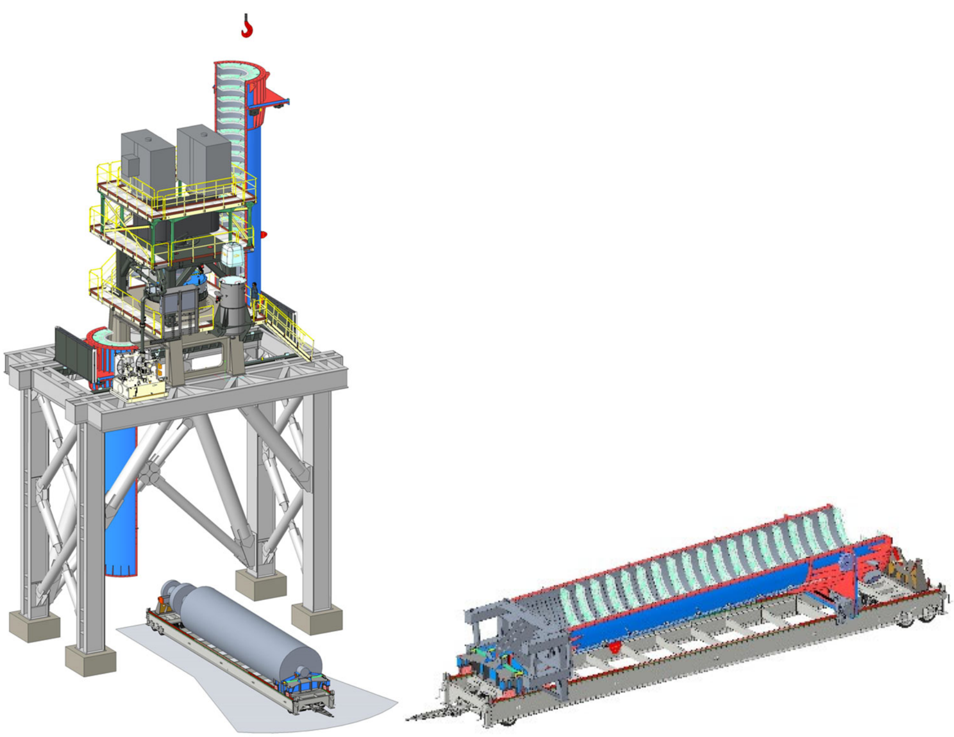

Figure 16—Maintenance of VRM 75000

Conclusions

Based on experience and using advanced scaling up methods, modern design tools, and a structural analysis approach, STM is introducing the world's largest stirred mill for secondary, tertiary, regrind, and ultrafine grinding applications. It extends STM's portfolio by a wide margin, reinforcing the company's position as the market leader in stirred milling.

The VRM 75000 mill can be equipped with a range of drivetrains from 7700 kW to 12500 kW, making it by far the biggest stirred mill on the market. It can achieve unprecedented capacity for a single unit, helping significantly reduce capital and operational costs.

VRM 75000's design has been scaled up from the existing VRM 50000, ensuring a smooth evolution of the well-proven concept. The mill chamber, which is fixed to the mill frame in a hanging design, has the same height-to-diameter ratio—4.3—with the mill gross volume increased to 75 m^3. The mill is driven by a multi-drive system consisting of two motors connected to a parallel shaft gearbox via torque-limiting couplings. If the maximum available installed power is not required, the mill can be equipped with a single drive unit similar to smaller mills. As applied on all STM mills, the VRM 75000 drive is paired with a VSD for mill speed control.

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