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How to Spec a Mill Gear

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

For optimal torque delivery as a function of cost, there are critical parameters that need to be communicated to the gear designer from the mill builder when designing gear drive systems for ore grinding applications. Apart from loads and speeds, interface dimensions and site specific conditions are also needed. Deciding up front which gear rating practice to select can affect the torque capacity of the drive train by ~15%. How to deliver the torque to the mill pinion, either by a gear reducer or low speed motor, influences the distribution of cost between the prime mover and the gear train. This paper will outline the design considerations that go into construction of the drive system in order to explain why specific data is required and where design freedom is necessary. A clear specification up front that allows for matching interface dimensions while allowing for the most cost efficient up front design achieves this goal.

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Introduction

An expert in whole-brain learning, Steven Snyder, once said

There are only two problems in life:

- (1) You know what you want, and you don't know how to get it; and/or*
- (2) You don't know what you want.*

To solve these two problems, a clear understanding and good communication skills are necessary. In terms of getting a great gear set, it requires a coordinated effort between the end user, the gear manufacturer, the gear designer, the consultant, and the original equipment manufacturer. Each of these groups has a key piece of the puzzle necessary for the gear to fulfill its useful operational life. This paper will outline what information needs to be collected and passed onto the gear designer to develop a successful drive train for a specific area of use: gearing for cylindrical grinding mills. It will act as a checklist for information required, outline the impact of certain selections, and resolve ambiguities to address the two problems outlined above.

Background

A grinding mill circuit is an unusual installation for gearing when compared to traditional enclosed gear drive installations, but these applications have been utilized for over eighty six years. The grinding process, more accurately termed a tumbling process, uses horizontal rotating cylinders that contain the material to be broken, potentially augmented by grinding media. See Figure 1.

The material moves up the wall of the drum until gravity overcomes centrifugal forces, and it drops to the bottom of the drum to collide with the remaining material. This breaks up the particles and reduces their size. Power required for this process ranges from 75 to 18000 kW (100 to 24000 HP), in either single or dual motor configurations.

In this type of application, the pinion is mounted on pillow blocks driven by a low speed motor or a motor and enclosed gear drive. The gear is mounted on the mill using a flange bolted connection (see Figure 2 for one type of flange installation). Both the center distance and alignment are adjustable either by shimming the pillow blocks or moving the mill. Lubricant is typically either high viscosity oil (1260 cSt @ 100°C) sprayed on the gear in 15 minute intervals or a lower viscosity oil or grease product sprayed on the pinion every few minutes. Alternately, lubrication can be applied by continuous spray or dip immersion methods.

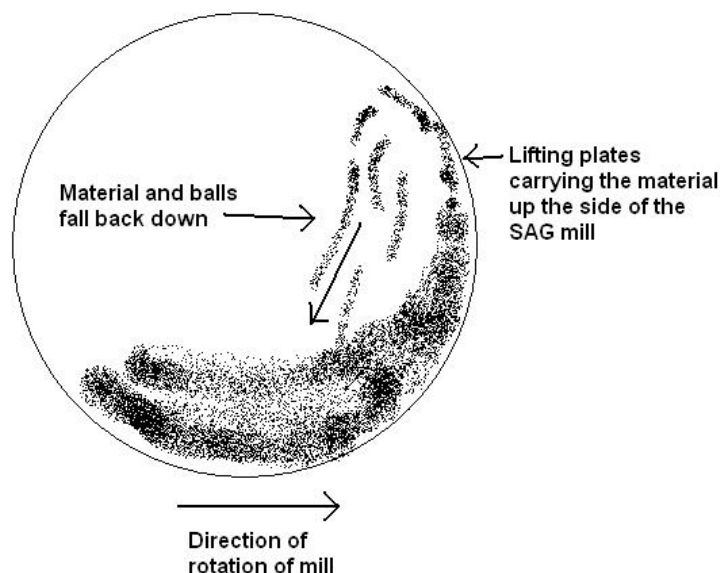


Figure 1. Grinding mill process



Figure 2. Grinding mill installation

Gear sizes can range up to 14 meters (46 feet) in diameter with face widths approaching 1.2 meters (50 inches). Typical tooth sizes range from 20 to 40 module (1.25 DP to 0.64 DP). Single stage reduction gears range from 8:1 to as much as 20:1. Gear materials are typically through hardened cast steel, fabricated forged and rolled steel, or spheroidal graphitic iron. Pinions are carburized, induction hardened, or through hardened heat treated steels. For small installations, either a one or two piece design is used with the split joints located in the root of a tooth. Four and six piece designs are also utilized when the weight of the segments exceeds the crane capacity of the facility or pouring capacity for cast segments becomes an issue.

Initial data

The purpose of a grinding mill is to make large rocks into small rocks. To accomplish this task involves significant calculations on the part of the mill builder. These include reviewing the size of the incoming and outgoing product, the rate of production, the size of the mill in diameter and length, the grinding media, the theoretical critical speed of rotation, and the interior configuration of the mill. Unfortunately, to get what is required, this information needs translation into something that the gear designer can input into the rating calculations. The calculation of actual contact stress s_c does not have an input for tons/hour of mineral produced.

A theoretical relation of mill diameter to power is $\sim \text{mill diameter}^{2.5}$. To get torque, we also need the speed of the drum. This is based on the concept of a *Theoretical Critical Speed of Rotation (CS)*. The critical speed of rotation is the speed (in rpm) at which an infinitely small particle will cling to the inside of the liners of the mill for a complete revolution.

$$CS = \frac{43.305}{\sqrt{\text{Mill Diameter}}} \quad (1)$$

where

CS is the theoretical critical speed of rotation, and is the mill speed, rpm;

Mill Diameter is the nominal inside diameter of the mill, m.

Since we actually need the particles to come off the inside diameter of the mill to be processed, the typical mill speed is $\sim 75\%$ of the theoretical critical speed of that mill. Using the above formulas, significant experience of how the grinding process works, and material properties of the ore being ground, the mill builder can provide the gear designer with input power and output speed.

The next step is the interface dimensions. Since the gear needs to turn the mill, it needs to have a bore larger than the mill outside diameter. The mill outside diameter is a function of the grinding process selected. Autogenous mills are the largest in diameter since the feed grinds itself. A semi-autogenous mill uses some metallic or ceramic balls to assist the grinding process and can be slightly smaller. Ball mills are smaller still and use a larger percentage of balls to perform most of the work. Large diameter mills allow for use of gear ratios not normally thought possible in single reduction applications, namely 8:1 to 20:1.

If the gear is to replace an existing gear, then manufacturing drawings or installation drawings complete with gear attributes, center distance and dimensions are required. Although budgetary pricing can be made without dimensional data, once an order is present, full data is required. These gears are made custom for each installation so there are no catalogs available to provide this information.

Site specific considerations also need to be disclosed. If the gear is expected to operate outdoors or in unheated structures, a minimum and maximum temperature range should be given to assist in lubricant selection and method of application. Transportation limitations can also affect the design. If crane capacity or size limitations exist, the gear designer can increase the number of segments of the gear to allow for reduced handling weights.

Rating standards

Once mill diameter has been established, the largest cost driver is the actual size of the gear. Gear power capacity is a function of how the ratings are calculated. There are two basic rating practices in use in gearing, ISO 6336 [8] and ANSI/AGMA 2001-D04 [5]. Both exist to provide a common basis for comparing the power capacities of various designs. By their nature, these are general standards in that they apply for fine pitch gears of 4 mm in diameter as well as 13000 mm gears, made from various materials and accuracy grades. Given that range, we run the risk of missing significant size effects, either large or small, or client expectations that will affect the performance of a gear set. This is why the general standards suggest use of an application based standard when designing gears for a specific purpose. The rating committee uses the fundamental standard as a criteria and method source for rating gears and adjusts the component factors to match experience and field performance for existing designs. AGMA and to a lesser extent ISO, has developed application standards for a variety of applications such as enclosed drives, high speed units, drives for wind turbines, marine, automotive, steel mill rolling applications to narrow the scope of the general rating practice and fine tune it for the nature of service.

For grinding mill service, an early application standard was AGMA 321.05 [3]. It was first approved for use in October 1943. Various iterations occurred with the last major re-write in 1968 when the standard was updated to use the formulations of AGMA 211.02 [9] and AGMA 221.02 [10]. The last editorial corrections were issued in March 1970.

This rating practice uses concepts that predate our current AGMA 2001 thinking. The rating formulas for gearing in this standard are:

$$P_{ac} = \frac{n_p d^2 C_v}{126000} \frac{F}{C_m} I \left(\frac{s_{ac}}{C_p} \right)^2 C_H^2 \quad (2)$$

$$P_{at} = \frac{n_p d K_v}{126000} \frac{F}{C_m} s_{at} \frac{J}{P_d} \quad (3)$$

where

- P_{ac} is allowable transmitted power for pitting, HP;
- n_p is pinion speed, rpm;
- d is operating pitch diameter, in;
- C_v is dynamic factor pitting;
- F is face width, in;
- C_m is load distribution factor;
- I is I factor;
- s_{ac} is allowable contact stress number, lbs/in²;
- C_p is elastic coefficient, (lbs/in²)^{0.5};
- C_H is hardness ratio factor;
- P_{at} is allowable transmitted power for bending, HP;
- K_v is dynamic factor bending;
- s_{at} is allowable bending stress number, lbs/in²;
- J is J factor;
- P_d is transverse diametral pitch, in⁻¹.