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Gear Material Selection and Construction for Large Gears

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Gear Material Selection and Construction for Large Gears

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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 gears larger than 3 m (10 feet) in diameter, construction of gear blanks tend to be divided into cast steel, ductile iron, and forged rim welded web structures for use in cylindrical grinding mills and kilns. This paper will review the application, various options for material selection, and the impact of selection on tooth geometry. A group of sample gears are developed to compare each of the materials and methods of blank construction. Each sample is discussed in light of structural stress, deflection, expected life, handling weight, material origin, fabrication method, inspection requirements during construction, and impact of selection on field performance. Based on the above, a road map is developed listing critical considerations and optimal use of each material and method of construction in this application.

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Introduction

The purpose of any gear mesh is to transmit rotary motion and torque from one location to another at a consistent rate. Various rating practices from AGMA, ISO, and others go into great detail about the tooth proportions, accuracy requirements, material selection, and cutting methods to produce a tooth that satisfies the requirements of the application. However, standards do not provide all information necessary to make sure the torque at the gear tooth is actually moved to the piece of driven equipment, i.e., gear blank design. In most enclosed drive applications, a disk of the same face with a bore and keyway is sufficient. However, when in the realm of large gears, defined as 3 m (10 feet) in diameter and above, a solid blank fulfills the design engineer's maxim of making the part difficult to manufacture and impossible to install. Blank design needs to be driven by the application and the range of materials available to ensure sufficient stress capacity is available at the teeth, as well as the ability to connect with the driven equipment. This paper covers these issues in a specific area of use: gearing for cylindrical grinding mills and kilns.

Background

Grinding mill and kiln service are unusual installations for gearing when compared to traditional enclosed gear drive installations, but these applications have been utilized for over eighty five 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. 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. Kilns rotate at far slower speeds to enable even firing of their contents. 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. For mill applications, the gear is mounted on the mill using a flange bolted connection (see Figure 1 for one type of flange installation). For a kiln, various types of spring plates are used. 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 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 rolled steel, or spheroidal graphitic iron. Pinions are carburized, induction hardened, or through hardened 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 weight or pouring capacity becomes an issue.

Structure requirements

Based on the application, these gears need to have large bores to accommodate the mill or kiln shell. This enables use of reduction ratios not normally thought of as reasonable (i.e., 8:1 to 20:1) in a single stage. The gears are bolted to the mill through a flange connection or mounted on tangential spring plates to allow for thermal growth. See Figure 2.

The next step is to connect the bore of the gear to the teeth. This is done by either using a Box, also known as a Delta or Y shape, or tee shape structure. See Figure 3.

A typical ring gear has a series of windows cut into the material for handling and weight considerations, as shown in Figure 4.

Over time design rules have been developed to address the material shape distribution of the various elements of the ring gear structure. Rexnord has over 5000 gears in service with design lives exceeding 25 years that confirms these rules and calculations are reflect field requirements. The purpose of the structure is to provide stability at the tooth location to ensure the assumptions made at the rating phase of gear development are supported by the actual blank design. Annex C of ANSI/AGMA 6014-A06 discusses the following considerations for blank design

- reduction of strength rating by moving the location of bending fatigue failure into the gear rim from the tooth root (K_{Bm} factor);
- effect of rim deflection on the load distribution factor, K_m ;
- influence of the mating element on load distribution factor, K_m ;
- definition of dynamic alignment techniques to achieve correct mesh patterns.

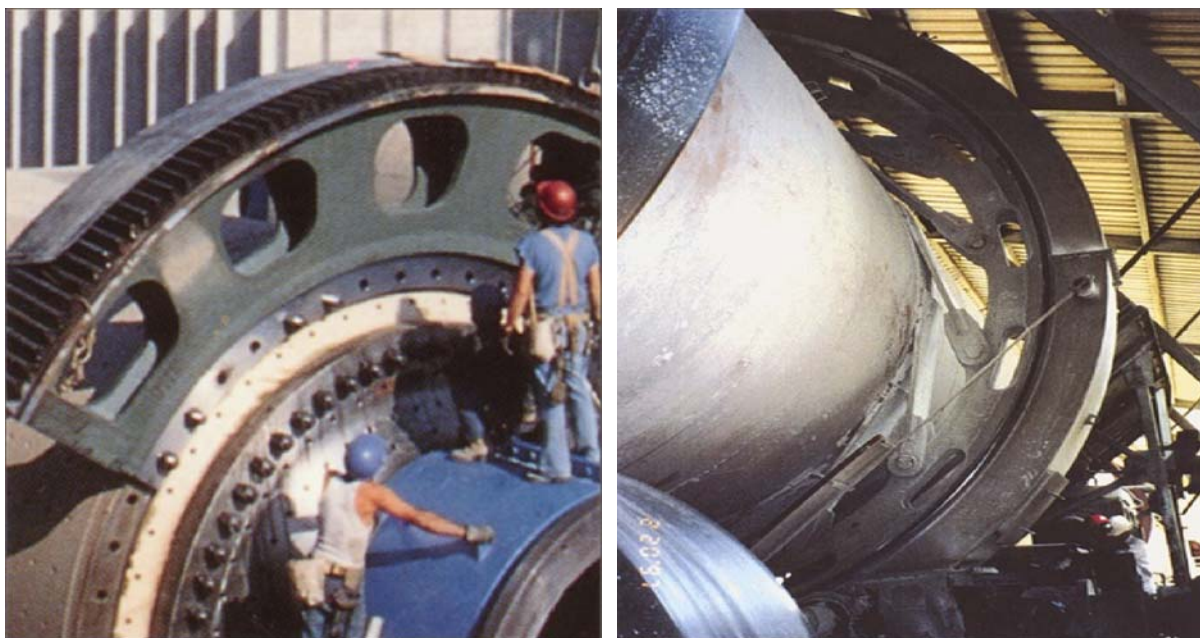


Figure 2. Flange mounting and spring mounting options

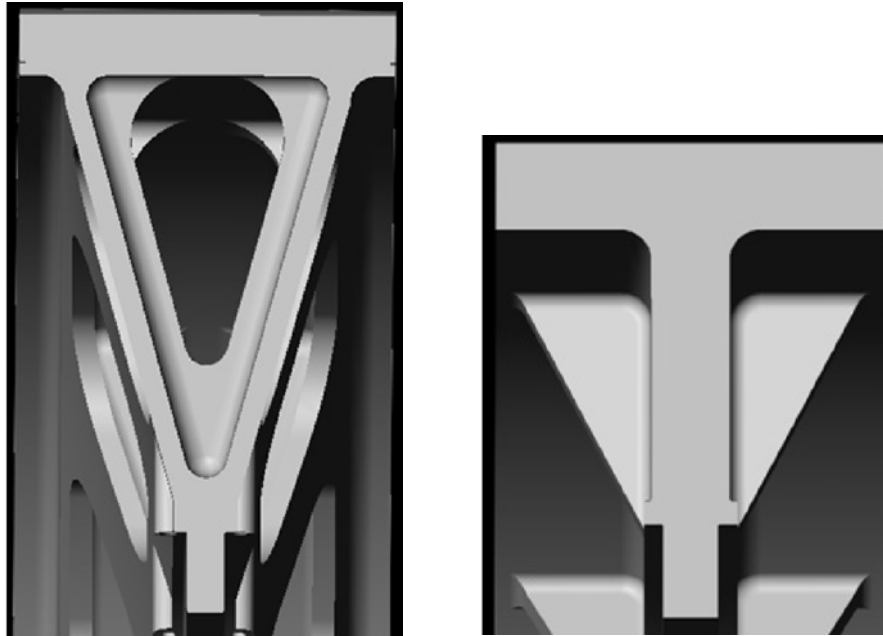


Figure 3. Box/Y/delta and tee shape cross section

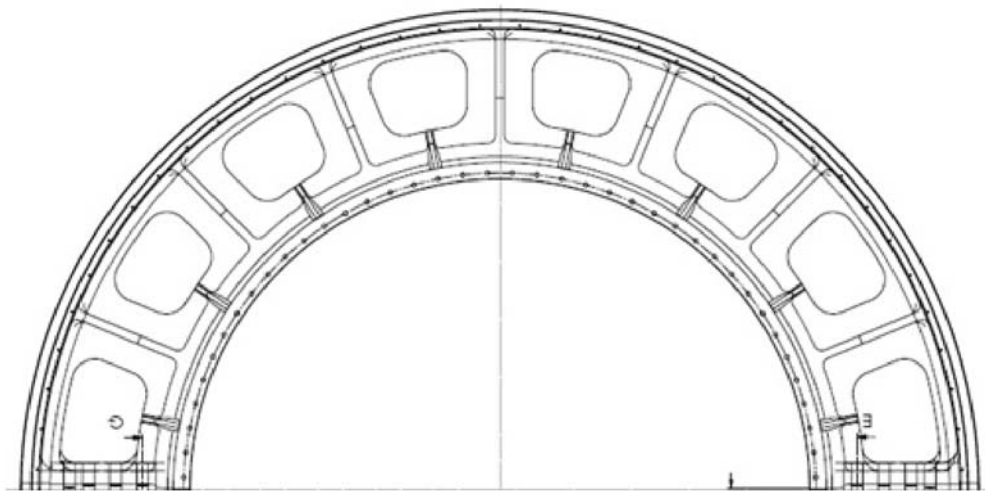


Figure 4. Side view of ring gear

Rim thickness is a significant parameter in the design. There is a minimum value of the thickness specified by the rating standards to ensure any bending strength failure of teeth would travel through the base of the tooth and not through the rim of the blank. Based on field experience, AGMA 6014 suggests designs having a backup ratio $m_B > 1.0$

$$m_B = \frac{t_R}{h_t} \quad (1)$$

where

m_B is back-up ratio;

t_R is gear rim thickness below the tooth root, in;

h_t is gear tooth whole depth, in.

This avoids the need to derate the gear to move the failure mode to a more conventional area. Other standards, such as ANSI/AGMA 2001-D04, feel a value of 1.2 is more appropriate. A point of debate is what