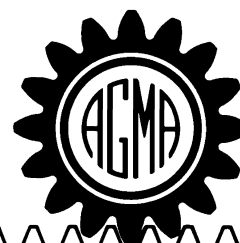


The Application of Very Large, Weld Fabricated, Carburized Hardened & Hard Finished Advanced Technology Gears in Steel

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American Gear Manufacturers Association



TECHNICAL PAPER

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Raymond J. Drago, Roy Cunningham, Steve Cymbala, Drive Systems Technology, Inc.

[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

In the 1980's, Advanced Technology Gear (ATG) steel rolling mill gear drives consisting of carburized pinions in mesh with very large, weld fabricated, high through hardened gears were introduced to improve capacity. Recently, even the improvements obtained from these ATG gear sets were not sufficient to meet higher production rates and rolling loads. For greater load capacity ATG sets have been developed consisting of carburized, hardened pinions in mesh with very large, weld fabricated, carburized and hard finished gears. Single and double helical gears of this type, ranging in size from 80 to 136 inches pitch diameter have been implemented in several steel rolling applications. This paper describes the conditions that require the use of these gears and the technology required to design, manufacture, and, especially, heat treat, these very special, very large gear sets.

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500 Montgomery Street, Suite 350
Alexandria, Virginia, 22314

October, 2005

ISBN: 1-55589-867-X

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Foreword

In the early 1980 time frame, the use of Advanced Technology Gear (ATG) Sets consisting of carburized, hardened, & hard finished pinions in mesh with very large, weld fabricated, high hardness, through hardened & hard finished gears was introduced as a means of improving the load capacity of existing steel rolling mill, Figure 1, gear drives.

The results of this innovation (Reference 1) were and continue to be excellent in that the life of the gears is extended dramatically and the quality of the rolled steel product also improves due to the much smoother operation of these ATG gear sets.



Figure 1. Steel Rolling Mill Overview

We have successfully applied this concept to a large number of steel mill gears. In addition, the ATG concept has also been equally successfully applied to other industries including mining, paper manufacturing, printing, waste water treatment, industrial mixers, and a number of other diverse applications.

Recently, however, in a number of steel mill applications, even the improvements obtained from these ATG carburized/through hardened gear sets were not sufficient to meet the ever higher production rates and rolling loads. In order to meet these needs for greater load capacity, we have developed ATG sets consisting of carburized, hardened, & hard fin-

ished pinions in mesh with very large, weld fabricated, carburized, hardened & hard finished gears for steel mill gear drives. Single and double helical gears of this type, ranging in size from 80 to 136 inches pitch diameter have been designed & manufactured and successfully implemented in several steel rolling applications. Several such gear sets are now in service and are providing excellent performance relative to the predecessor gears that they have replaced. Several additional gear sets are now in various phases of manufacture and will be placed in service in late 2005. This paper describes the conditions that require the use of these fully carburized gear sets and the technology developments required to design, manufacture, and, especially, heat treat, these very special, very large carburized gear sets.

Advanced Technology Gearing

The ATG concept is actually a comprehensive gear design and manufacturing system including design parameters, material specifications, geometry modifications, and quality control that is implemented by a very detailed written specification that controls the entire Design, Manufacturing, and Quality control of the gear set and, where required, the entire gearbox system as well. The ATG concept has long addressed carburizing as the pinions within this system are usually (but not always) carburized and hardened. The extension to carburized, weld fabricated gears is an extension of the basic ATG concept and requires additional controls on the manner in which the large carburized gears are manufactured to facilitate the carburizing process while retaining all of the advantages associated with the initial ATG basis.

Introduction – The Rolling Process

As Figure 2 shows schematically, the rolling process, be it for steel or aluminum, is a deceptively simple process. As is often the case with apparently simple concepts, the details of the processing itself

are complex and require careful study to yield good results.

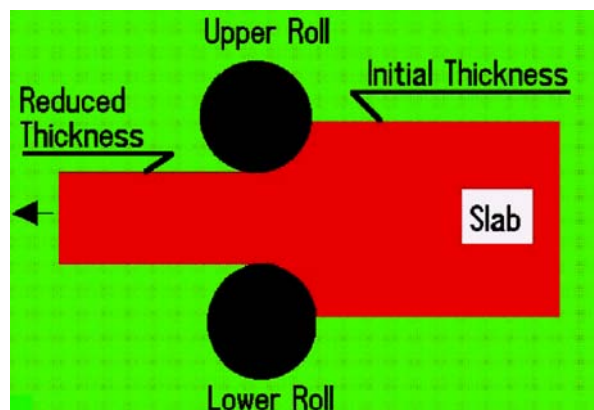


Figure 2. The Rolling Process - Simplified

Essentially, the process involves converting a relatively thick narrow short slab of hot steel into a somewhat wider, considerably thinner, and much longer piece of sheet steel. The specifics of the process depend on the desired final product (e.g., automobile body panels, appliance cabinets, etc.) and the composition and strength of the steel being rolled. In the most remote way, the process is analogous to rolling pizza dough! The operating conditions loads, temperatures, speeds, and duty cycle are, however, infinitely more severe. The design of the gear drives that power the rollers is a complex task that requires a good combination of manufacturing and design engineering. Rolling mills may be of the hot or cold rolling type as well as several variations within these broad categories (tandem mills, Steckle mills, etc.). Of these, the hot rolling mills tend to be the most severely loaded and will be our main focus here.

Typically, the steel passes through several roughing stands, such as the one shown in Figure 3, and then through several finishing stands. The roughing stands do most of the work on the initial slab while the finishing stands (which are very similar to the roughing stands in general construction and kinematics) refine the gage shape and surface properties of the final product.

Each stand is driven by an electric motor (sometimes by two motors in series), typically with a nameplate rating in the range of 8,000 to 12,000 HP. The motors are connected to the drive system via

couplings (typically gear couplings though elastomeric elements are occasionally used). The drive system between the motors and the rolls is composed of a main gearbox (typically speed reducing for roughing drives and the first finishing drives and often, but not always, speed increasing for the final finishing drives).

The output from the main gear drive, which may be single or double stage arrangement, is connected via a shaft with couplings at either end (often called a torque tube) to a mill pinion gearbox. The mill pinion gearbox is a 1:1 arrangement whose function is to divide the power from the main gearbox's single output shaft to two shafts that subsequently drive the rolls. The output shafts from the mill pinion drive are connected to the mill rolls via relatively long shafts known as spindles. Because of the need to move the rolls up and down the spindles incorporate special high misalignment couplings at both ends. These couplings may be of the "slipper" type (typically used on older mills) or specially designed highly crowned and modified gear couplings (typical of newer or updated mills).



Figure 3. Typical Roughing Rolling Stand

Single or double helical gears are used almost universally in these gearboxes. Figure 4 shows a typical, much generalized schematic of a rolling mill drive system. In some systems (particularly, for example, in tandem mills), the mill pinion and main gearboxes are combined into one, integrated gearbox. Each element of the drive system (i.e., motors couplings, spindles, main and mill pinion gearboxes, shafts, etc.) presents its own unique set of challenges ...and gear technology opportunities!

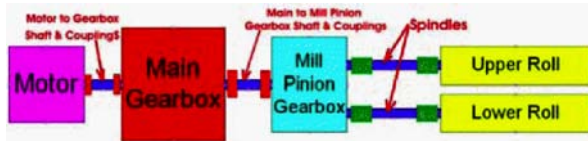


Figure 4. Rolling Mill Drive System Schematic

Our focus here, however, will be the gears used in the main gearboxes, both roughing and finishing. These gearboxes tend to have very large, weld fabricated gear members, such as that shown in Figure 5, which can significantly benefit from the application of this technology.



Figure 5. Typical Large Rolling Mill Gear Set

Loading

The loading on the mill gear system is obviously very important; however, the real loading spectrum is not usually obvious and is seldom simple. Actual torque measurements have shown that the torque transmitted by each gear mesh is not well represented by the torque equivalent of the motor nameplate power and speed. Because of the very high inertia in the entire system and the dynamic conditions that occur as the rolls bite into the steel slab and proceeds to change both its shape and structure, Figure 6, the torque that is applied to each gear mesh in the system is different and varies significantly as the bar progresses through the rolling process.

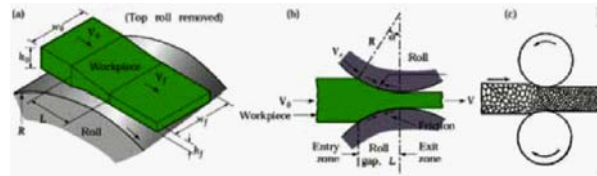


Figure 6. The Basic Steel Rolling Process

One would, of course, expect a difference in torque on the motor to main gearbox and main to mill pinion gearboxes due to the ratio of the main gear drive. This is true; however, strain gage measurements, such as those shown in Figure 7, show that the difference in torque is often not proportional to the gear ratio alone. This plot shows torque measured on various shafts in the system as a function of time.

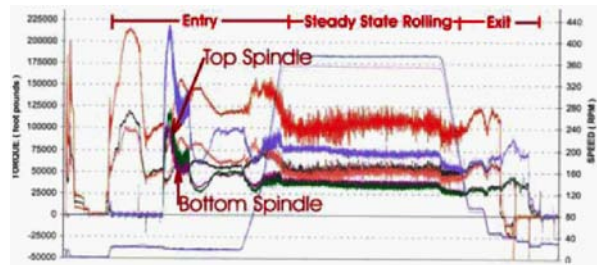


Figure 7. Torque Measured on Various Shafts in a Steel Rolling Mill (strain gage measurements)

Note that the torque variation is particularly high during entry of the bar into the rolls and then it settles down to a more stable "variation" pattern finally dropping off as the bar exits the mill. Motor power, as measured by motor current, also varies but to a far lesser extent as the system inertia "insulates" the motor somewhat from these very wide load variations. Because of this, measurements of motor power or motor current are generally poor indicators of the torque applied to the gear mesh and very often under-predict the gear mesh loading. This can lead to premature gear failure and bearing life problems.

Considering these factors, from this data plot, it should be obvious that the torque measured is not just a function of the motor power and the gear ratio but also of the system dynamics. Note that the torque experiences significant variation as the bar enters and exits the mill. Even during the actual rolling process the torque alternates significantly in many cases.

While we are dealing with the main gear drive here, it is also interesting to note that the torque carried by

the upper and lower spindles (and thus the torque absorbed by the top and bottom rolls) is not equal. Our design requirement for this torque split is a 60/40 split to either shaft. This split represents the usual expected “worst” case but we have observed splits as high as 70/30 to these two shafts.

This variation of torque is often referred to as the Torque Amplification Factor (TAF). The TAF is best understood by considering the simplified torque load schematic shown in Figure 8.

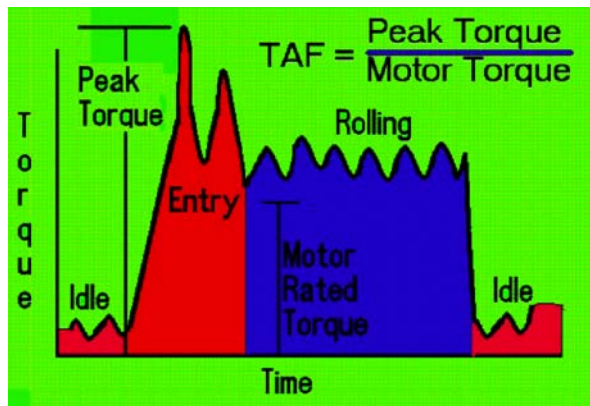


Figure 8. Simplified Torque Schematic

In order to properly design the gear and bearing system, it is necessary to have a reasonable knowledge of the TAF for any system. The TAF can be calculated by creating a dynamic model of the entire mill system or it can be measured through the use of strain gages applied to the various shafts. It can also be estimated based on experience but such estimates are fraught with the possibility of error as each system is quite different. In any case, the TAF must be properly addressed. The discussion of loading is especially important in our context because, unlike most gear applications, the design of the gearing itself can significantly impact the loading that the gear set will be required to transmit. Many, older mill gears were manufactured with relatively light webs and stiffeners and equally thin rims under the gear teeth, as the failed gear in Figure 9 shows. Note that the gear shown in Figure 9 is a cast gear but it is also representative of the configuration of many weld fabricated mill gears as well.

The teeth on such gears were often hobbled or, sometimes, shaper cut to AGMA Quality levels in the range of 6 to 8. At these quality levels, the combined pitch line runout of the gear and its mating pin-

ion is such that the backlash in the gear set was usually quite high, even considering the relatively coarse diametral pitch typical of mill gears (pitch is generally in the range of 0.75 to about 2.0). Typical backlash for these gear sets would be in the range of 0.060 to over 0.100 inch, depending on quality and pitch. When the bar enters the mill and begins its journey between the rolls, as is clear from Figures 7 and 8, impact loading is applied to the entire system. This loading is fed back through the gear system. Backlash in the gear system exacerbates the effect of the impact loading thus minimizing backlash is a desirable. In order to allow the backlash to be minimized, the gear quality level must be increased. A typical set of ATG mill gears, of a size similar to the set shown in Figure 5 would have a backlash in the range of 0.025 to 0.040 inch. This lower backlash greatly reduces the TAF thus the gear tooth design itself can reduce the applied loading.

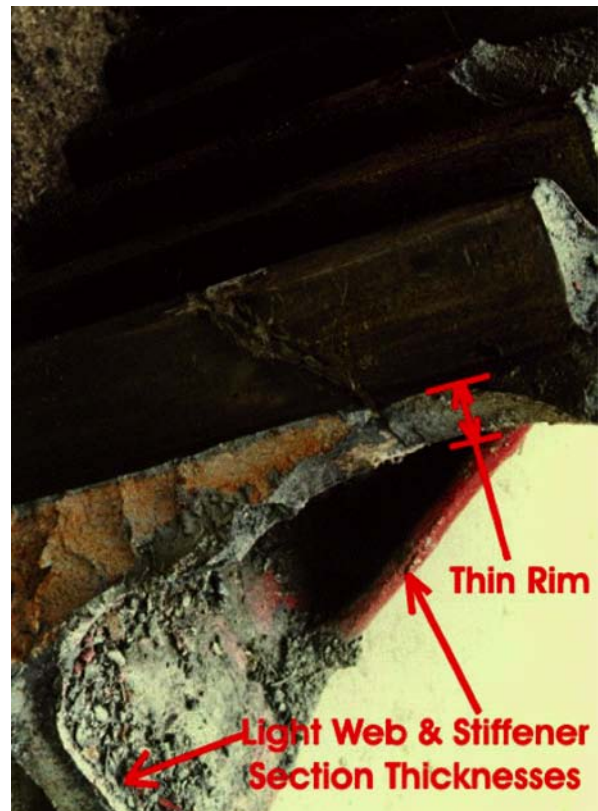


Figure 9. Failed Roughing Mill Gear

In addition to providing dramatically improved strength and stiffness (discussed in more detail below), the greater overall mass, thicker gear rims, heavier webs & stiffeners act to increase the inertia