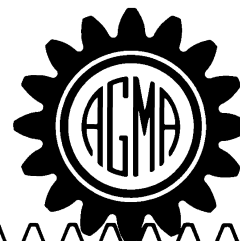


A Crane Gear Failure Analysis – Case Study, Observations, Lessons Learned, Recommendations

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American Gear Manufacturers Association



TECHNICAL PAPER

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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

Cranes, large and small in a very wide variety of types, are ubiquitous in just about every industrial environment. Many have been in service for 20, 30, and 40 years or more! This is especially true for very large cranes such as those used in heavy industrial environments including metals processing, automotive manufacturing, mining, etc. The basic technology of crane design has advanced in many areas including motors, controls, human interface, and wire rope design, among others. One area that has not changed very much over the years, however, is the design and manufacture of the gearboxes that form major links in the overall crane system. In general, the gearboxes used in cranes have proven themselves to be reliable work horses capable of delivering years of service with minimal maintenance. Recent crane gear failures (one of which, most unfortunately, resulted in a fatality), however, gave rise to a reevaluation of the design, configuration, and manufacture of the gearboxes in large cranes.

In addition, as part of a recent failure investigation, it became obvious that while the cranes themselves are subjected to routine, thorough safety inspections, the internal gearbox components are not generally evaluated periodically by skilled gear technologists trained to recognize potential gear system problems. For example, in a recent, special series of crane gearbox internal inspections gear defects of a potentially serious nature were identified in more than 37% of the gearboxes examined!

Since crane gearboxes do not operate either for long periods of time or “continuously,” as do most other geared systems, gear system fatigue characteristics have not been in the forefront of crane gear system operation. Recent studies have, however, indicated that in many cases usage rates and loading and, in many cases’ both have increased dramatically. In some applications, “production” (loaded crane usage) has increased by factors of two or three or even more while unit loading has similarly increased. This much higher usage makes the cumulative effects of fatigue much more important in these typically intermittent use devices.

This paper presents a case study of one particular crane gear failure, including both the failure analysis and resultant remedial actions, along with a discussion of the results of and implications from extensive gearbox inspections that were conducted as a result of the initial failure. Based on this experience, additional analyses were conducted on historical inspection data that provided the basis for a critical analysis of crane gear usage, failure incidence, and design practices. In addition, recommendations for specific actions required to insure crane gearbox safety and improve reliability in today’s much more challenging environment are presented and discussed.

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500 Montgomery Street, Suite 350
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October, 2006

ISBN: 1-55589-894-7

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The Initial Incident

In the spring of 2004, a failure occurred in a large industrial crane system. As the crane was lifting a heavy load, the load became “hung.” That is, it was neither possible to raise the load further nor lower it to the floor. Since such problems are often related to electrical issues including motor failure and controls issues, an electrician was dispatched to trouble shoot the problem. The electrician climbed aboard the crane trolley and proceeded to work the controls while observing the motor shaft. He observed that the shaft turned in the appropriate direction when the controls were activated. A mechanic was then dispatched to examine the mechanical portion of the crane, including the gearbox.

The mechanic examined the couplings and other visible portions of the drive system but found no apparent problems. The sheet metal cover, similar to that shown in Figure 1, of the final drive spur gear set was then removed so that the gears could be visually examined.

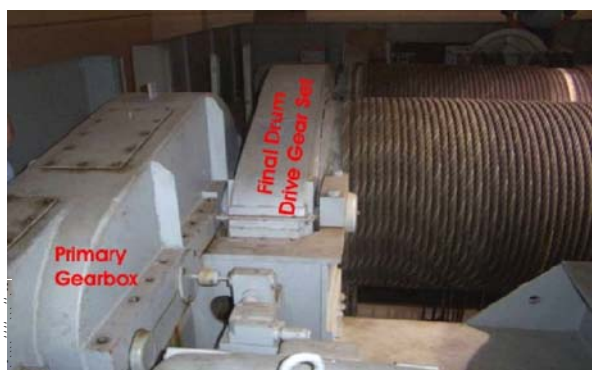


Figure 1. Primary Gearbox, Final Drive Spur Gear Set Case and Wire Rope Drum

As he was examining the final drive spur gear set, the mechanic observed an object that appeared to be wedged in the gear mesh. He reached into the gearbox with a tool in an attempt to free the object from the mesh. Unfortunately, when he did so, the load dropped immediately and precipitously. As the load crashed to the floor, the wire rope spun from

the drum in an over speed unwrap. The mechanic was ensnared by the whipping rope and, tragically, injured fatally. The electrician who was watching a short distance away on the crane trolley was not injured but was seriously shaken by the experience.

The crane system was immediately taken out of service and similar cranes in use were also taken out of service while an investigation into the cause of the failure was mounted.

The Failure

Subsequent to securing the site, as the gearbox was being examined, it was discovered that the object that the mechanic saw in the gear mesh was a piece of key stock. Examination of the gearbox continued in an effort to determine the source of the key. The spur pinion was found to be a shell design, similar to that shown in Figure 2, which is press fit on the output shaft of the primary drive gearbox. A keyway in the bore of the pinion accepts a key that provides torque transmission from the shaft to the gear. This is the key that became entrapped in the gear mesh.



Figure 2 - Shell Pinion With Keyway

The pinion that was installed in the failed gearbox, Figure 3, experienced a tooth fracture failure. Examination of this pinion shows clearly that it cracked through the rim, at the keyway.



Figure 3 - Failed Final Drive Spur Pinion

While the failure itself is due to fatigue, it is very important to note that the mode of failure, cracking through the rim rather than a tooth fracture, is the primary cause of the loss of torque transmission capability of the pinion when the crack progressed. This is a clear instance of a thin rimmed gear failure by cracking through the rim. In addition, careful examination of the keyway shows that the corners of the bottom of the keyway are quite sharp with virtually no significant radius present. This condition exacerbates the thin rimmed configuration and provided a very definite crack progression path.

As Figure 4 shows, when a gear blank has a thick rim, if a crack initiates in the tooth root, the progression path is across the base of the tooth, ultimately liberating either a piece of the tooth or, if the face is narrow, the entire tooth.



Figure 4 - Comparison of Thick and Thin Rim Failure Modes

When the gear rim is thin, it “participates” in the tooth bending and the stresses at the tooth root change character dramatically, as Figure 5 shows.

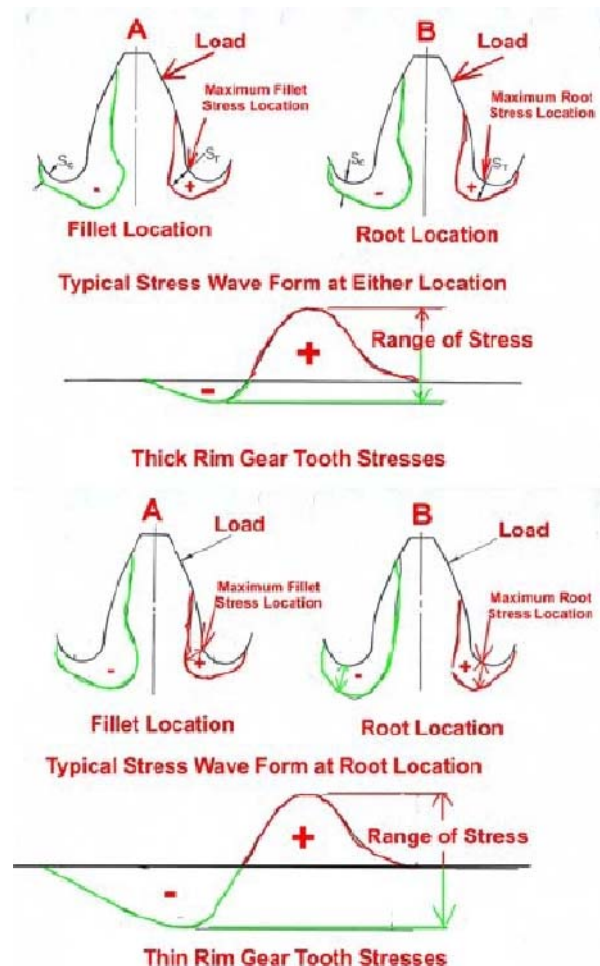


Figure 5 - Comparison of Fillet Stress Wave Forms for Thick and Thin Rimmed Gears

Careful examination of the stress wave forms in Figure 5 shows that both the magnitude and the position of the maximum range of stress changes as the rim gets thinner. The results of these changes result in a change in failure mode (i.e. crack propagates through the rim rather than through the tooth base) and an increase in stress level. Considering this scenario, it is easy to understand how the shell pinion failure shown in Figure 3 occurred.

This phenomenon was first described in detail and brought to the forefront when a new factor, the Rim Thickness Factor, K_b (Figure 6), was added to AGMA Standard 218 based on the work presented in Reference 1. This factor was carried forward when AGMA 218 was replaced with AGMA Stan-