Issue **FOCUS:**
MAINTENANCE

"Out of sight, out of mind" problem for dryer section gears can lead to unexpected gear failure caused by harsh machine conditions

BY AL LANKFORD and RUSS FOX

Scheduled Dryer Gear Inspection Reduces Unscheduled Downtime

PAPER MACHINE DRYER SECTION GEARS operate in harsh environments. They are subject to high torque loads, contaminated lubricants, and temperature extremes. Given their location on the backside of the machine, these gears often do not receive sufficient maintenance attention, the result of which can be unplanned—and costly—downtime due to gear failure.

Identifying and diagnosing problems in the gearing of the dryer sections can be difficult. While many paper machines are similar, each has its own unique drive system and operating conditions. These distinctive various gear arrangements, speeds, temperatures, materials, bearings, and operating loads add complexity to the maintenance programs, and make troubleshooting problematic. Still, with diligent effort, the root causes of gear wear and failure, as well as substandard operation, can be identified and corrected, improving the performance of the machine drive, and with it, paper machine performance.

A LITTLE HISTORY. From the late 1800s until the mid-1960s, cast iron spur gears in an open arrangement were the predominant method of delivering drive torque from the in-drive to the individual dryers. By today's standards, the paper machines of this era were narrow with moderate speeds. In the 1950s and 1960s, non-metallic spur gear materials began to appear as a solution to the high noise and vibration levels that were the result of the large cast iron gear meshes. Replacing every other gear with a non-metallic gear reduced both noise and vibration, and also reduced the need for lubrication. Today, nylon is the non-metallic "material of choice" for gears, with nylon gear operating on some of the widest machines in the world at machine speeds up to 3,300 fpm.

FIGURE 1: *Misalignment is one of the easiest problems to spot.*

As paper machine widths and speeds increased, paper machine builders began using helical gears in enclosed gear cases. The change in gear shape—from spur to helical—was driven by the superior torque transmission capability of helical gears, which results from having more tooth area in contact during mesh. Enclosed gear cases provided the mounting for gear arrangements, protection from large contaminants, and the opportunity to continuously apply lubricants to gear assemblies by the addition of an oil bath. The oil bath provided both superior lubrication and a method of removing small contaminants with the lubrication system's filters.

Advances in the design, materials, and manufacturing process make today's replacement gears stronger, longer lasting, and more efficient. Full root radius tooth structure, new heat and impact resistance nylons, and upgrading from cast iron to ductile iron for pinions and enclosed gearing have resulted in improvements in gear operation and life. Installed and maintained properly, dryer gearing will operate trouble-free for many years.

DYNAMIC INSPECTION. A "diligent effort" to understand and affect gear wear and failure begins with regular inspection. This includes dynamic visual inspection, static visual inspection, and static measurement of gear dimensions.

Dynamic inspection consists of using the strobe light to "freeze" the image of the gear mesh while the gear assembly is operating. Such an inspection, prior to maintenance shutdowns, is helpful in identifying

FIGURE 2: *Scoring is caused by a failure of the lubricant film.*

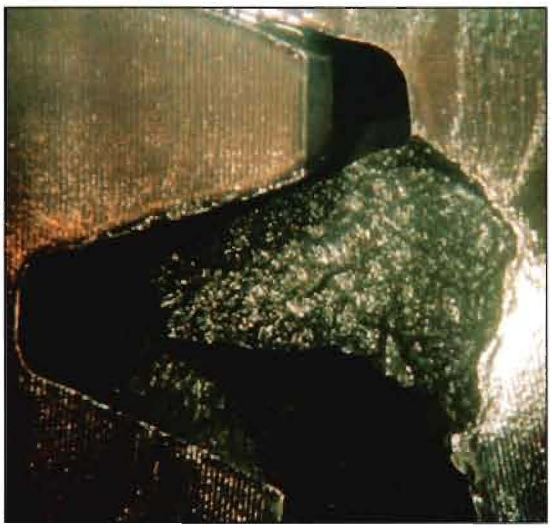


FIGURE 3: *Fatigue breakage results from repeated bending stresses greater than the endurance limit of the gear.*

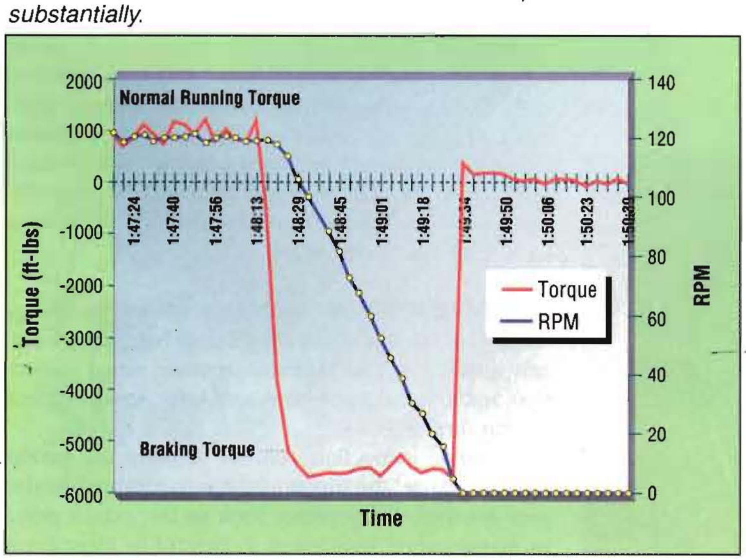


FIGURE 4: *Sudden deceleration can increase torque loads substantially.*

areas for a more detailed static inspection during the shutdown. While dynamic visual inspection is easy to perform on open gear assemblies, it requires the removal of the inspection covers in the case of enclosed gear assemblies. Alternatively, some mills have installed Plexiglas access covers to make inspection easier.

For enclosed gear assemblies, candidate areas for dynamic visual inspection can be identified during a "walkdown" of the drive side of the machine. "Growling" or other noises coming from the gear assembly indicate gear mesh problems.

"Backdrive," one problem that can be identified through dynamic visual inspection, is a condition where the drive gear is being driven rather than driving. Under a strobe light, the inspector will see that the gear teeth are meshing on the wrong side in relation to their direction of rotation. Such back-driven gears cannot correctly transmit power through the assembly. Typically, this results in an overdrive condition elsewhere in the gear system.

Backdrive (and the resulting overdrive) can be caused by excessive draw between sections, speed mismatch between sections, high felt tensions, and variations in dryer "can" diameters. In the case of excessive draw between sections, the downstream section gearing will provide the torque required to drive its own dryers, as well as some (or all) of the torque required to drive the upstream dryers. As a result, the downstream gearing is subjected to higher loads, stress, and wear.

Another common cause of backdrive is the removal of gearing elsewhere in the gear train. When a gear is removed downstream from the pinion, the felt must deliver the full drive torque load of the section. The felt continues to carry this torque on the return run, transmitting the torque back into the upstream gears and pinion. This results in additional loading.

Variations in dryer diameters are especially detrimental when combined with high felt tensions. An undersized or oversized dryer will vary in surface speed at its outside diameter relative to the adjacent dryers. If the dryer can is undersized, it will attempt to rotate faster than the adjacent dryers and the gear will backdrive the adjacent gear. As a result, significantly more power will be transmitted through the gears than they were designed to carry, subjecting them to overdrive conditions.

Gear meshes that appear to "float" from overdrive conditions to normal drive conditions may be transition points from backdrive to appropriate drive. Alternatively, such floating can be an indication of variations in speed between dryers. This type of speed variation is often caused by dryer imbalances and can be traced to water in the dryers, internal balance weights that have become loose, or loose siphon and/or spoiler bars. A brief internal inspection of the dryer during the next shutdown is appropriate when such conditions are found.

Fluctuation in the backlash, or in "tip-to-root" clearance, indicates that the gear is not concentric, that the journal upon which it is mounted is bent, or that the center-to-center distance between gears has shifted (Figure 8). Excessively tight (or loose) backlash, or excessive tip-to-root clearances, indicate a worn bearing, misalignment, or worn gear teeth.

STATIC VISUAL INSPECTION. Open gearing can be visually inspected with relative ease during routine maintenance outages. Each gear should be checked for cracked, missing, broken, or otherwise damaged teeth. Since the greatest tensile stress is applied at the tooth root, this is the area where cracks are most likely to appear, especially in nylon gears.

The tooth profile should also be examined. If the teeth have flat flanks or pointed tips, they have worn

A few calculations

Although the center distance for a pair of dryers and their gears can be very difficult to measure in the field, the change in center distance can be mathematically determined from the measurements of tooth thickness and backlash.

For example, consider a spur gear with 110 teeth, 2-in. circular pitch (CP), a pressure angle (PA) of 14.5°, a pitch diameter (PD) of 70.0282-in., and a total backlash (BL) at the gear mesh of 0.060-in. If no backlash allowance is made, the new tooth thickness is 1-in. However, the thickness of the new gear teeth will be cut to 0.970-in. so that each gear contributes half of the total backlash to the mesh:

A. (1-in. – 0.970-in. = 0.030-in.) x 2 = 0.060-in. (BL)

The tooth thickness (TT), plus the total backlash, equals the circular pitch for two identical mating gears:

B. 0.970-in. (TT) + 0.970-in. (TT) + 0.060-in. (BL) = 2-in. (CP)

If, upon inspection, we measure the following at the mesh point of two mating gears:

Tooth thickness gear #1 (TT#1):	0.920-in.
Tooth thickness gear #2 (TT#2):	0.930-in.
Measured backlash (MBL):	0.080-in.

Based on the measurement of tooth thickness, and referring to calculation B above, the backlash should be 0.150-in. if the center distances have not changed:

BL = CP – TT#1 - TT#2

2-in. (CP) – 0.930-in. (TT#1) - 0.920-in. (TT#2) = 0.150-in. (BL)

However, in this case, the backlash measured is 0.080-in. Therefore, the center distance is tighter than standard. Then we can perform the following calculation to determine the change in backlash clearance:

Measured Backlash (MBL) - ([(thickness gear #1] + [(thickness gear #2)] = ΔBL

C. 0.080-in. - [(0.970-in. - 0.920-in.] + (0.970-in. - 0.930-in.)] = (-0.010-in.)

Due to the reduction in backlash clearance of 0.010-in., there will be an interference if new gears are installed in this location. The backlash will have to be increased by spreading the center distances before new gears can be installed. The amount that the center distance will have to be increased can be determined by using the next equation (where CD is the center distance).

D. ΔBL = (CD (2) tangent PA

We can solve for (BL by using the calculated backlash (CBL) and measured backlash (MBL):

E. (BL = CBL - MBL (0.150-in. (CBL) - 0.080-in. (MBL) = 0.070-in. Δ(BL)

We can then solve for (CD by the following:

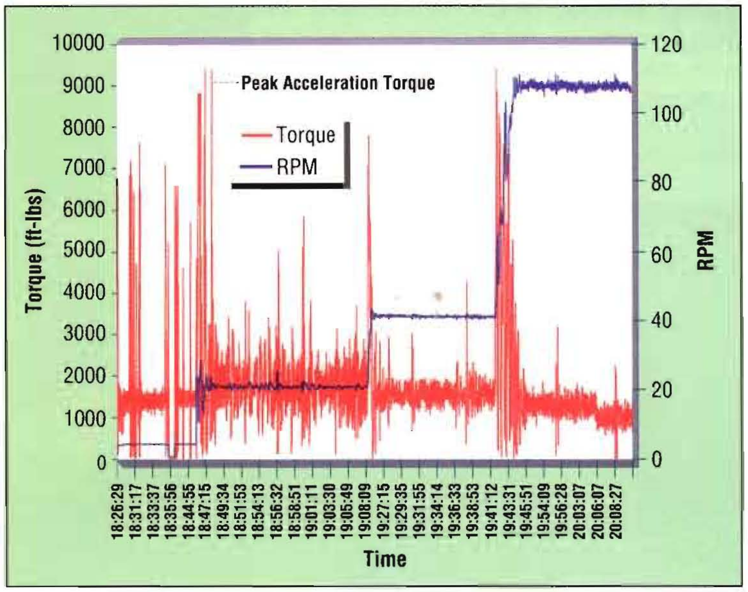
ΔCD = (BL tan PA (2)

ΔCD = 0.070 = 0.1353-in. tan 14.5°

In this case, the backlash between the two gears has been reduced 0.070-in. by a reduction in center distances between the two gears (and dryers) of 0.1353-in., or better than one-eighth of an inch. As the total gear wear is 0.090-in., these gears have not crashed. If the gears had not worn, this change in center distance and reduction of backlash would have caused the teeth to crash. The center distance must be adjusted before two new gears can be installed.

This method can determine if excessive backlash is caused by worn gear teeth, a change in center distance, or both. Slight changes in center distance can be identified that will not be noted otherwise and, ideally, should be performed for every mesh in the gear train. Corrective actions can then be planned. In many cases, changes in center distances will be due to bearing wear and the bearings can be targeted for inspection. (Note: The above example is for spur gears only. For helical gears, the helix angle must be accounted for in the calculations.)

FIGURE 5: *Torque overload can also occur during quick accelerations.*



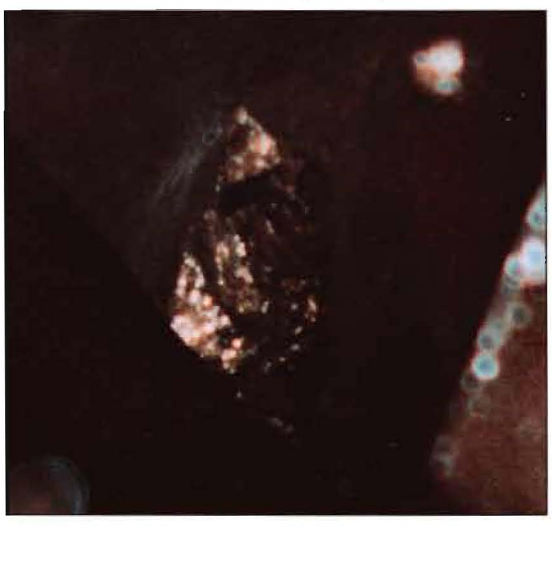
to the point that they will no longer mesh smoothly. This lack of smooth mesh increases noise, vibration, and also the rates of further wear. Finally, the alignment of gear faces should be evaluated, as should tip-to-root clearances and evidence of backlash. In the case of nylon gears, the inspection should confirm that all clamp ringbolts are in place.

Enclosed helical gears are subject to the effects of corrosion and abrasion from contaminants over time. These assemblies are also susceptible to damage that can result from the breakdown of the lubricants. These longer-term modes of deterioration result in material loss and, with it, tooth strength.

Visual inspection should evaluate the following types of wear conditions:

Misalignment. When the gears are not properly aligned, the drive loads are concentrated at the edge of the teeth resulting in higher compressive loads, accelerated wear, uneven wear, and ultimately, failure (Figure 1).

FIGURE 6: *Localized failure is caused by large contaminants passing through the gear mesh.*



Abrasive wear and scratching. This surface wear phenomenon is caused by fine particles passing through the gear mesh. It is characterized by a slightly roughed tooth face with very fine scratch marks. Minor amounts of abrasive wear and scratching will not necessarily reduce gear life. More severe or chronic wear—generally associated with chronic lubricant contamination—can substantially reduce gear life.

Scoring. More radical scratching and grooving on the tooth is caused by a failure of lubricant film during localized overheating of the gear mesh (Figure 2). The resulting metal-to-metal contact can cause rough points on the tooth flanks to weld together instantaneously. As the rotation continues, the welds break, tearing out tooth material. Left unchecked, scoring can remove sufficient metal over time, resulting in destructive wear. The root cause of scoring damage is often fatigued or improper lubricant and/or inadequate lubricant filtration.

Destructive pitting. Repeated application of stresses beyond the endurance limit of the material can result in this form of surface fatigue. It causes metal to be removed from the surface and is evidenced by inverted cone-like cavities along the tooth face. The damage usually starts below the pitchline and progresses as size and number of pits increase.

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Rolling and peening. Also forms of surface fatigue, rolling and peening are caused by sliding action under excessive loads and coincident impact loading. They result in the formation of rolled metal along the edges of the tooth. The tooth face may also take on the appearance of a surface that has been peened by a tiny peening hammer. The damage is generally caused by overload conditions including overdrive, backdrive, excessive draw, and flooded dryers.

Fatigue breakage. When bending stresses greater than the endurance limit of the gear are applied repeatedly, breakage can ensue (Figure 3). Cracks begin to form in the root on the loaded side of the tooth—the area subject to the greatest tensile stress. Under continued stress, the cracks propagate until tooth failure occurs. While operation beyond recommended wear limits is the most common cause of breakage, skewed loading from misalignment can also cause this type of damage.

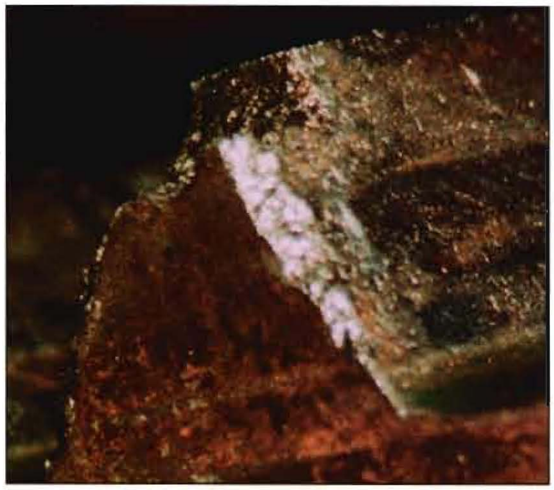
Localized failure. The passage of large contaminants through the gear mesh can result in localized failure (Figure 6). Although the damage might appear to be minor (i.e., some operators might be tempted to return the gear to operation), any defect in a gear tooth transfers stress to the adjacent gears with which it meshes.

Destructive wear. Excessive wear causes tooth-shaped deterioration (Figure 7). Such wear can be caused by any one, or a combination of, the various types of surface wear which are described above. If not corrected by replacement of the affected gear(s), destructive wear can result in a catastrophic failure of gear teeth. In enclosed gear assemblies, this type of failure can cause the destruction of the entire gear section.

Open gearing can be visually inspected with relative ease during routine maintenance outages. Each gear should be checked for cracked, missing, broken, or otherwise damaged teeth.

Overload breakage. While overload breakage is not necessarily a wear condition, it merits mentioning. Overload typically results from sudden shock loads, which stress the gear beyond its endurance limits. A common cause of such overloads is inappropriately high acceleration and/or deceleration rates. Many paper mills have elected to reduce the deceleration time of their paper machines. This is sometimes accomplished by the installation of auxiliary brakes on the dryer section in-drives. This practice can result in substantial deceleration torque forces (Figure 4). This, of course, produces severe

FIGURE 7: *Destructive wear is the deterioration of the tooth shape caused by excessive wear.*



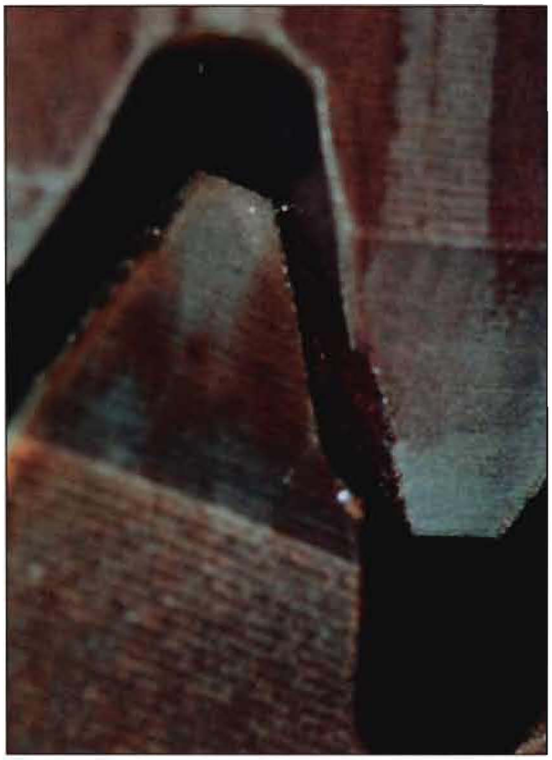


FIGURE 8: *Excessive backlash can be caused by service-induced increases in the center distance between the mating gears.*

stress conditions in the dryer gear teeth during deceleration.

Overload stresses can also occur during acceleration cycles (i.e., when acceleration rates are excessive), resulting in tooth breakage during the startup cycle (Figure 5). Hard starting clutches and misalignment can also cause gear failure due to overloading.

In addition to visual inspection—dynamic and static—preventative maintenance programs should include measurement of critical gear parameters. In the case of paper machine dryer gearing, these parameters are tooth thickness, backlash, and engagement (see sidebar, "A few calculations," page 89). ■

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