Preventive Maintenance:

An Examination of the Root Causes of Gearbox Failure

Contents

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About Philadelphia Gear

A founding member of the American Gear Manufacturers Association (AGMA), Philadelphia Gear, a brand of Timken Gears & Services Inc. offer products and services found in use worldwide; from conveyor gear drives used in underground mining operations, to emergency repair services critical to the power generation industries. The company serves thousands of customers across the globe from its regional service and manu-facturing facilities in New Castle, DE; Birmingham, Alabama; Mokena, Illinois; Houston, Texas; and Santa Fe springs, California, and is headquartered in King of Prussia, Pennsylvania.

When equipment fails, often a plant manager's biggest concern is how to get the equipment running again. However, equally important to getting it back online is discovering 1) why the equipment failed, and 2) how such a failure can be prevented in the future. But often, plant managers and their employees are ill-equipped to identify the cause or causes of such problems, ultimately leading to their recurrence.

Preventive maintenance is defined as the regular performance of equipment maintenance practices in order to avoid future equipment problems. An important first step in any preventive maintenance program is learning to identify the causes of equipment failure. Once the cause of failure is determined, one can take steps to avoid the problem in the future. That is the purpose of this paper – to provide plant managers and service technicians with the knowledge to identify causes of gearbox failure – a crucial link in the power transmission chain – with the hope that it will lead them to establishing an effective preventive maintenance program of their own.

1. LUBRICATION/OIL ANALYSIS

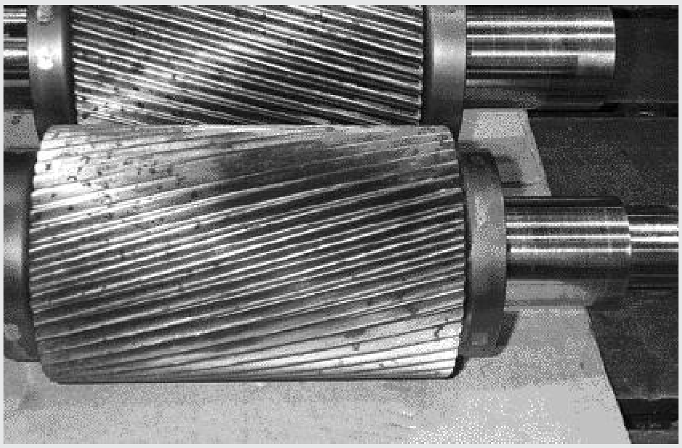
Always important when there is potential metal-to-metal contact, effective lubrication is extremely critical to all gearboxes. Proper lubrication will help prevent both gear and bearing failure. In contrast, many gear and bearing failures result from insufficient or interrupted lubrication.

Maintaining proper lubrication necessitates following proper lubrication practices. These include selection of the appropriate lubricant, keeping oil clean and free of foreign materials, and maintaining a sufficient supply of lubricant. Because selecting a lubricant is based on so many independent factors – gear type, load type, speed, operating temperatures, input power, reduction ratio – choosing a lubricant should be left up to a gear lubrication specialist. This is especially true when you consider the technical sophistication found in gearing today, along with increased speeds and loads, and the specialized lubricants and additives now available.

Lubrication shortcomings can cause several gear problems. Failures, like scoring and galling, are generally caused by oil film breakdown resulting in metal-to-metal contact, and high temperatures resulting in tooth surface damage. If a gear continues to operate without adequate lubrication, damage will progress until the gear tooth profiles are degraded to the point where gear tooth kiss grinding or gear element replacement are the only remedies. Abrasive wear may also occur as the result of foreign materials present in the lubricant.

1.1 CASE HISTORY

Such a lubrication problem caused a catastrophic failure in a gearbox on an offshore gas production platform. The gearbox, designed for high-speed compressing applications, required an externally "force-fed" lubrication system, as opposed to an internally designed splash lubrication system. The failure of this system caused severe damage to the gearbox – lack of lubrication caused the bearing babbitt (an alloy material used to line the sleeve bearings) to actually melt within seconds of the failure. The gear set soon became overheated, causing the gear teeth to crack and break apart inside the gearbox. This cracking was most likely the result of misalignment caused by the initial bearing damage.

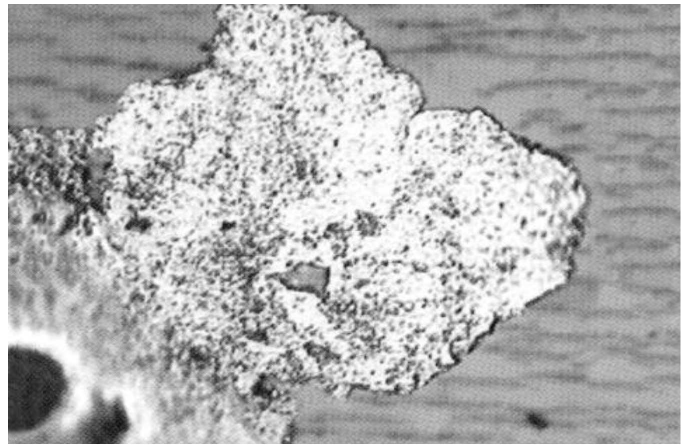


Lubrication failure led to severe damage to the gearbox (above)

The offshore platform had only one gearbox installed – a compressor drive used for pumping natural gas through undersea lines directly to processing plants located on shore – so when the gearbox failed, it effectively shut the platform down. If the teeth had not been broken, personnel on the rig would have attempted to repair it by simply changing the sleeve bearings and repairing or replacing the external lubrication system.

Fortunately, a set of "through-hardened" gears was provided in rapid fashion to operate at a reduced service factor until their unit was rebuilt. This allowed the platform to meet a particularly important production deadline. However, such a problem may have been prevented if an adequate maintenance plan for the unit had been in place. Ultimately, the unit was rebuilt with replacement case-hardened gear elements.

Maintenance professionals have several important tools at their disposal for diagnosing gearbox lubrication problems. One of these tools, oil analysis, plays a crucial role in not only preventing such problems, but in assessing the overall health of equipment.

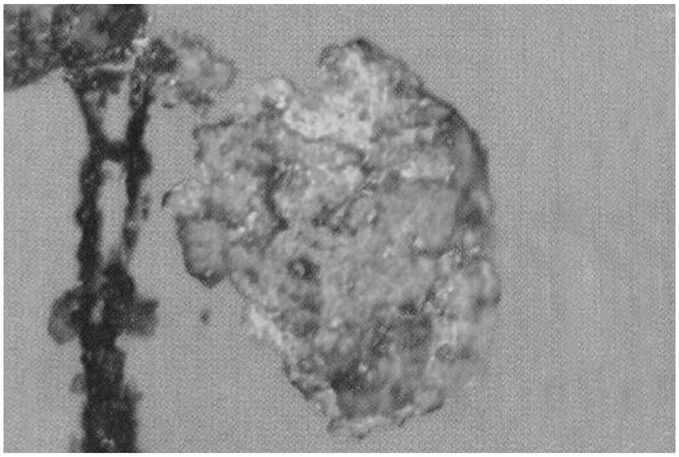


White metal particle misaligned with magnetic field

By analyzing particulate content and concentration in the oil, engineers are able to monitor the condition of an operating gearbox. Further analysis of the oil yields vital information concerning the condition of the lubricant used in the equipment.

Analysis of the oil used for lubrication could alert engineers to possible problems within the lubrication system. Equipment that had exhibited frequent mechanical problems, or that which would cause an outage if it fails – such as the compressor drive – needs to be checked regularly for possible lubrication problems.

Further, lubrication problems can be detected by examining wear patterns on gears. Gear tooth "pitting" is characterized by a large number of very small pits, distributed evenly over the working surface of a gear. The appearance of such pitting is usually an indication of gear overload, but it may also be indicative of lubrication problems caused either by some corrosive medium within a lubricant, or by improper lubricant additives.

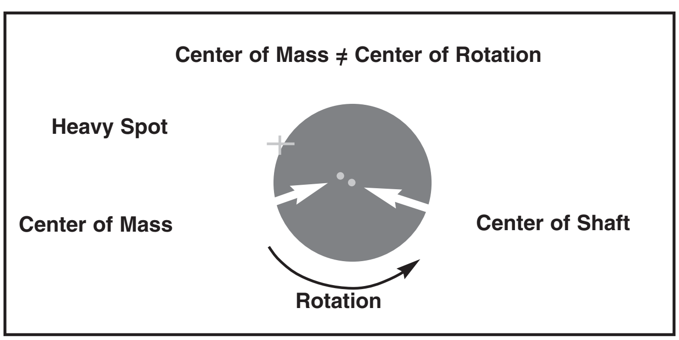


Sample of magnified oil analysis indicating roller contact failure

2. VIBRATION ANALYSIS

Vibration – the motion of a body about a reference point caused by an undesirable mechanical force – is a key indicator in the diagnosis of machine faults. Each machine fault generates a specific vibration profile, and a single vibration measurement provides information concerning multiple components. The frequency of the vibration is determined by the machine geometry and operating speed.

By analyzing shaft vibration, engineers are able to determine whether the cause of the machine fault is imbalance, misalignment, general looseness or wear, bearing defects, gear defects, or some other unforeseen problem.



Imbalance can cause other gear faults to appear

Imbalance is the force created by a rotating body when its center of mass is offset from its center of rotation. High radial peaks at 1x shaft RPM, low axial vibration at 1x shaft RPM, low harmonics of shaft RPM, and 1x RPM sinusoidal pattern in the time waveform characterize imbalance. Imbalance can cause other faults to appear. Once a structure is vibrating, any number of ancillary components can become loosened. Hardware and piping are good examples of items that are loosened due to excessive vibration.

Misalignment is the deviation from a common centerline during operation. Misalignment can occur as offset (shafts are meeting square, but not on a common centerline), angular (shafts are meeting at an angle from one another), or both. Gear damage caused by misalignment is visible as a fracture originating at one end of a gear tooth, occurring on a diagonal line. Misalignment is also a common cause of broken teeth on helical and bevel gears.

Often, misalignment is the result of loose bearings, resulting in shaft deflection and, later, a possible gear tooth fracture. Part of any preventive maintenance program would include the inspection of such bearings to ensure they are running with the proper clearance and are in satisfactory condition. Checking proper adjustment is often part of such a program. Otherwise, significant gear damage is possible.

Wear is another fault determinable by vibration analysis, and can cover a broader range of gear damage, from scoring and galling, to abrasive wear, to plastic yielding.

Plastic yielding – a severe flow of surface material resulting in lip ledges at the end of gear teeth – may occur on gears subjected to heavy, continuous load, as well as gears subjected to intermittent heavy loads or overload.

2.1 CASE HISTORY

Left alone, any of these machine faults can do enough damage to necessitate shutting down a process. For example, a sugar cooperative had reported a "bump" in their low-speed mill drive (one of four such units on-site). The noise became more noticeable, and the customer was ultimately forced to shut the unit down. After a thorough investigation, it was determined that it was not feasible to try to repair the unit before the current sugar-processing season was over. The bull gear was damaged, necessitating a long lead-time for repair.

The damaged bull gear was re-rimmed

It was determined that the bull gear could be re-rimmed, rather than replaced entirely. Ultimately the drive was repaired, but such equipment damage is costly, both in terms of repair, and the process time lost without that drive in operation.

While it isn't definite that vibration analysis would have determined the cause of the "bump" prior to its appearance, such preventive maintenance practices give engineers sufficient data to analyze the health of a gear, as well as provide them with the data they need to determine the cause of failures after-the-fact. Vibration analysis can be applied to track the health of equipment and aid in scheduling gearbox maintenance, to preclude unscheduled equipment or process shutdowns.

3. MACHINERY OPTIMIZATION

Preventive maintenance measures are taken not only to ensure equipment is kept running; these efforts are also made to keep equipment running at peak output levels. This often means uprating a gearbox for optimum output based on its application. By performing a detailed review of a gearbox and its application, engineers can determine the equipment's uprate potential, and in many instances, a gearbox can be uprated by upgrading rotating elements without adversely affecting existing gearbox interface requirements.

In contrast, lack of preventive maintenance often results in the opposite. Equipment in use from different manufacturers, and maintained irregularly, often is not operating at peak levels, or worse, is used at levels exceeding maximum output recommendations. In these cases, preventive maintenance practices can be taken to calibrate machinery so that it is operating at optimum levels – before it becomes a problem.

4. ENVIRONMENTAL FACTORS

As potentially damaging as equipment failures, environmental factors often place equipment under strains that it was not designed for – whether corrosion from a humid environment, or lack of maintenance due to inaccessibility.

Lack of accessibility to cooling tower drives (due to the fact that elevation of cooling towers often exceeds 80 feet) sometimes leads to poor-to-nonexistent maintenance procedures. In addition, equipment found in moist, humid environments is more susceptible to failure due to corrosion, as moisture inside the gearbox can eventually accumulate, contaminate the oil and destroy the bearings.

Compounding the problem, safety concerns often do not allow for inspection of the units while they are running. This certainly was the case with an oil refinery mentioned in the next case history. Consequently, this negatively affected the inspect/repair procedures and tended to render cooling tower drive failures a mystery.

4.1 CASE HISTORY

In some instances, maintenance practices can not only lead to getting the most out of the machinery in use, but also getting the most out of unused equipment. For example, a major oil refinery had replaced a number of cooling tower drives, and were accumulating the used units on-site, with no clear idea as to when or if they would ever be utilized. The refinery used its cooling tower drives, typically about 10 units at any given time, to chill condensed steam generated by the manufacturing processes. Over this same period, the refinery had gone through a protracted downsizing effort. They no longer had the resources to inspect and repair the drives on-site. Thus, when a unit failed, a new one was purchased, and the old one was simply relegated to the “boneyard.”

Used cooling tower drives accumulated on-site

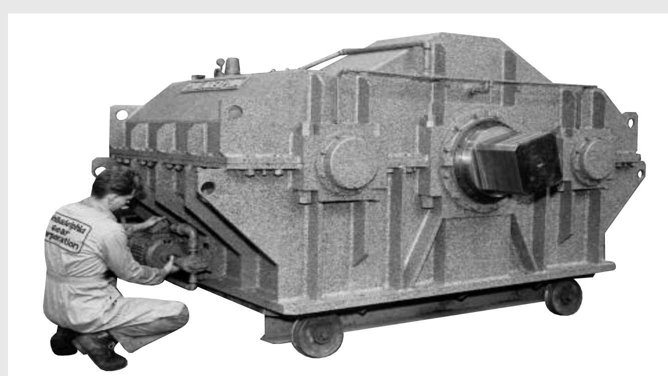
The customer had three different manufacturers’ drives in use. Several of the cooling tower drives had either become noisy, or operating vibration levels were above acceptable vibration thresholds. Rather than quoting on new equipment, a visual inspection of four units that had been shelved during the downsizing period was undertaken. It was concluded that the units could still be salvaged.

Gearbox components were combined to create two useable units

Ultimately, test results determined that by combining components of the four boxes, they could be reconditioned into two useable units. By taking this approach, the refinery was able to save 40 percent of the cost that would have been spent on new units.

4.2 CASE HISTORY

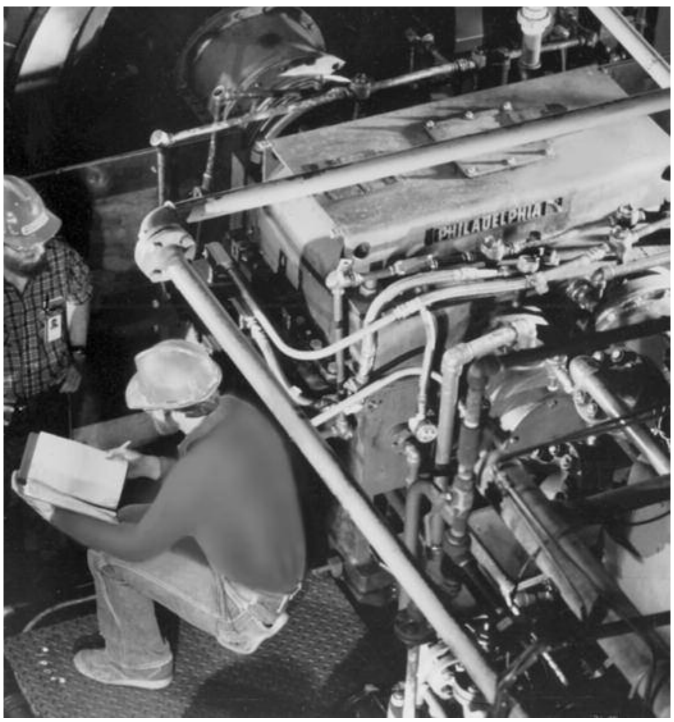
At the sugar cooperative mentioned earlier, an optimization problem was evident. Though the original gearboxes powering their mill drive had been designed to run at 800 HP (maximum 1000 HP), the turbines that they were supporting were upgraded five seasons before that to run at a maximum of 1800 HP, routinely running at more that 1200 HP since the upgrade took place. This necessitated an upgrade of engineering options available to increase these gear ratings to an appropriate level – including an immediate change to a new low-speed unit and an eventual change to a new high-speed unit.



Gear ratings at the sugar co-op were increased to an appropriate level

5. ESTABLISHING A PREVENTIVE MAINTENANCE PROGRAM

While identifying the cause of equipment failure can sometimes be as simple as looking closely at the damage, discovering the root cause of such a problem is often considerably more difficult. The bottom line is, most plants do not have the sophisticated equipment needed to identify shaft vibration anomalies or analyze oil samples for foreign materials. Without these resources, how then can they establish a preventive maintenance program?



Vibration analysis is an important component of any preventive maintenance program

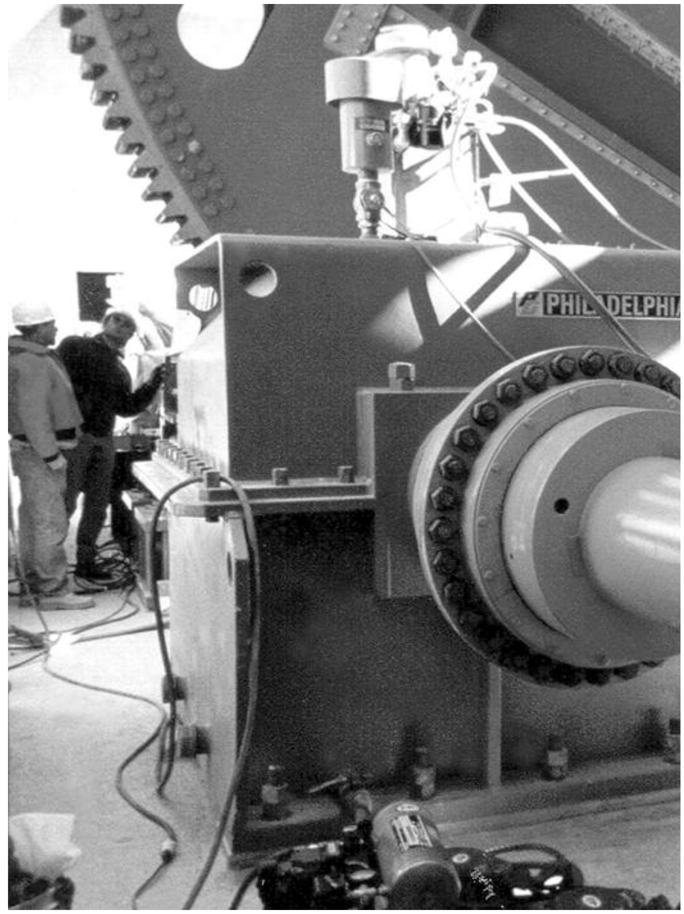
Outsourcing preventive maintenance functions to an outside service provider is certainly an option. Outsourcing these duties allows plants to focus on their own core competencies, letting experts, with access to both a strong knowledge base and a wide range of necessary equipment, handle maintenance and repair duties.

All gearing equipment will need maintenance at one point

When selecting a preventive maintenance provider, there are several key services that should be included in any agreement. Repair and overhaul services are a necessity, as ultimately all equipment will need maintenance at one point or another. The key is to plan that maintenance downtime so that it does not negatively affect production. Such services should cover breakdowns, scheduled maintenance, parts reconditioning, service upgrades, reverse engineering, alignment and balancing, and on- or off-site diagnostic services. Providers should be thoroughly skilled in performing gearbox failure root cause analysis. For repairs, full disassembly and cleaning, inspection and measurement, engineering evaluation, uprate recommendations, performance of repairs and spin tests should all be accomplished. In the case of catastrophic equipment failure, failure analysis is an important service.

Troubleshooting is another necessary service, as part of a comprehensive preventive maintenance program. Such troubleshooting duties include engineering assistance in identification, and swift resolution of operational problems. Other important services (mentioned earlier) include vibration and oil analysis. These two monitoring techniques are paramount in identifying equipment anomalies before they become a problem.

Any good preventive maintenance contract should include a strong warranty on all equipment serviced. Such warranties often offer many of the services already mentioned, and are ultimately a benefit to the refurbished equipment. Also, as important as any warranty is the proper installation of a gearbox*. Proper installation can assure years of trouble-free operation, provided that adequate preventive maintenance procedures are performed.



Proper preventive maintenance practices extend equipment life and ensure many worry-free years of operation

6. CONCLUSION

While identifying the cause of equipment failure is only the first step in establishing an overall preventive maintenance program, it is an important step. The information gathered will ultimately serve as the foundation for planning future preventive maintenance – a particular necessity when working with mission critical equipment. Such information will also help service technicians to avoid making the same mistakes after initial equipment repairs. Once this information is determined, working with a service provider to establish a complete preventive maintenance program is important in maintaining equipment for future use, as well as lowering equipment lifecycle costs.

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7. PREVENTIVE MAINTENANCE CHECKLIST:

Equipment Repair

- Breakdowns
- Scheduled Maintenance
- Parts Reconditioning
- Service Upgrades
- Reverse Engineering
- Alignment and Balancing
- On or Off-Site Services

Oil Analysis

- In-Service Condition Monitoring of Lubricant and Operating Equipment
- Wear Particle Analysis
- Monitor Mechanical Condition of Wearing Parts
- Monitor Lubricant Viscosity
- Measure Concentration of Contaminants

Vibration Analysis

- On-Site Diagnostic Assistance
- Phone Support
- Preventive Maintenance Program Support
- Turnkey PM Services
- System Design and Calculations

Troubleshooting

- Engineering Assistance in the Identification, and Swift Resolution of Operational Problems
- Analysis of Operational Problems Including:
  - System
  - Component
  - Sound
  - Vibration
  - Failure

Failure Analysis

- Determine Root Cause of Gear and Bearing Failures
- Evaluate Entire System
- Identify Root Cause and Permanent Corrective Action
- Operational Loads
- Component Design
- Maintenance Practices
- Failed Components

8. GLOSSARY OF TERMS

Abrasive Wear: Caused by foreign material found in a lubricant; identified by a satiny, lapped appearance and irregular tooth profile

Bearing Babbitt: An alloy material used to line the sleeve bearing

Failure Analysis: Root cause determination of a failure, examining operational loads, equipment design, equipment maintenance, and the failed components to determine failure cause and permanent corrective action

Galling: An advanced case of scoring

Imbalance: The force created by a rotating body when its center of mass is offset from its center of rotation; imbalance can cause other faults to appear, especially looseness

Lubrication: A film of oil used to prevent metal-on-metal contact of bearings

Misalignment: The deviation from a common centerline during operation; damage caused by misalignment is visible as a fracture originating at one end of a gear tooth, occurring on a diagonal line; misalignment is a common cause of broken teeth on helical and bevel gears

Oil Analysis: The analysis of particulate content and concentration in the oil in order to monitor the condition of an operating gearbox

Pitting: A large number of very small pits, distributed evenly over the working surface of a gear

Plastic Yielding: A severe flow of surface material resulting in lip ledges at the end of gear teeth

Preventive Maintenance: A regular performance of equipment maintenance practices in order to avoid future equipment problems

Reverse Engineering: By taking comprehensive measurements and manufacturing component parts to original specifications, a gear drive or assembly component part may be duplicated through reverse engineering

Scoring: The result of the failure, or lack of a lubricant; evident by small patches of seized area

Sinusoidal: Having a succession of waves or curves

Time Waveform: The mathematical representation of a wave, especially a graph obtained by plotting a characteristic of the wave against time

Troubleshooting: Engineering assistance in the identification, and swift resolution of operational problems

Uprate: Upgrading/adjustment of rotation elements within a gearbox for optimum output

Vibration: The motion of a body about a reference point caused by an undesirable mechanical force

Wear: A general term describing a broader range of gear damage, which encompasses scoring and galling, to abrasive wear, to plastic yielding

For more information on Philadelphia Gear visit us online at www.philagear.com.

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