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Maximum allowable torque

What is the maximum allowable torque of a gear and why does it matter?

When participating in a competitive sport, there is a strong desire to maximize the physical output of your body. Whether it is running faster or leaping higher, we all strive to push the boundaries of how we were designed. Sometimes these activities result in spectacular imagery, such as when we leap high into the air and catch a football in the end zone, scoring the game winning touchdown. Other times, they result in spectacular failure, such as when we land from that amazing catch and our femur cracks under the pressure. Engineers typically push the physical limits of gearing in a similar way to what athletes do to their bodies.

In order to properly size a gear for a specific application, design life is critical. If a gear needs to operate for a short cycle, perhaps one hour, then the applied torque can be significantly higher than if the same gear needs to operate for six months or more. A common design standard for gearing is 2,600 hours. This benchmark represents a gear being in service for eight hours per day, five days per week, for one full year, with a factor of safety of 1.25. With this time frame established, annual preventative maintenance can be scheduled on the mechanism to check for wear and other issues.

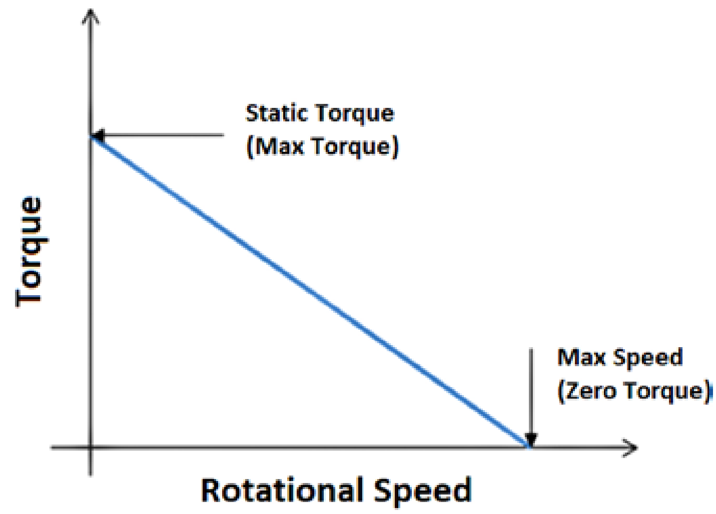

Figure 1: As the gear begins to rotate, the dynamic torque capacity decreases.

As torque capacity is inversely proportional to the operational speed of a gear train, the maximum allowable torque will vary depending on the speed of the driven gear. When a gear is not rotating, the maximum allowable torque is equal to the static torque. As the gear begins to rotate, the dynamic torque capacity decreases as noted in the Figure 1.

Just as the speed is important to the value of the maximum allowable torque, so is the definition of maximum allowable torque itself. Most engineers only consider the maximum allowable torque due to bending strength. This is the maximum applied torque that will cause an instantaneous failure of the gear. Another torque to consider is the maximum allowable torque due to surface failure. The failure mode, also known as bearing failure, is defined as the allowable applied torque that minimizes surface wear, thus allowing the gear to perform as designed for the desired life span. These two torque capacities are independent and can vary significantly.

Let us consider the following situation:

If we choose a module 2, 20 tooth, carbon steel spur gear, with a 20mm face width, operating at 100 rpm, symmetrically supported by bearings, properly lubricated, driven by a uniform load and a desired life of 107 cycles, then the maximum allowable torque due to bending strength is 46 Nm. However, the maximum allowable torque due to surface failure is only 2.83 Nm. With this gear, the surface torque capacity is only 6 percent of the bending strength torque.

If we choose a module 2, 40 tooth, carbon steel spur gear, with a 20mm face width, operating at 100 rpm, symmetrically supported by bearings, properly lubricated, driven by a uniform load and a desired life of 107 cycles, then the maximum allowable torque due

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to bending strength is 118 Nm. However, the maximum allowable torque due to surface failure is only 12.5 Nm. With this gear, the surface torque capacity is slightly better at 10.5 percent of the bending strength torque.

In order to improve the surface durability, a heat treatment is typically applied to the tooth surfaces. Dependent on the base material, the heat-treatment method could be laser hardening, carburizing, or induction hardening. Each of these processes increases the surface durability of the tooth flank but they also reduce the bending strength.

Using the same gears detailed above and induction hardening the tooth areas, we are able to significantly improve the maximum allowable torque due to surface failure. For the 20-tooth example, although the bending strength torque capacity drops from 46 Nm to 38.3 Nm, the maximum allowable torque due to surface durability increases from 2.83 Nm to 16.6 Nm. For this gear, a 17 percent decrease in bending strength results in a six-fold increase in surface durability. For the 40-tooth example, the bending strength torque capacity drops from 118 Nm to 98.3 Nm, and the maximum allowable torque due to surface durability increases from 12.5 Nm to 72.1 Nm.

As noted earlier in this article, if the desired life is shorter, then the maximum allowable torque values will be higher, and if the operating speeds are increased, then these values would be lower. The maximum allowable torque is never one static value. The designer must always consider all of the operating conditions in order to properly calculate the maximum torque values. Athletes, like gears, can suffer from bending strength failures, resulting in broken bones, and they can suffer from surface failures, resulting in hip and knee replacements. When operated properly, the service life of both athletes and gears can exceed their design life.

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