Engineering Reference

Gearmotors & Gearheads

Servo Market and Stealth Objective

Design engineers are continually looking to increase throughput and production requirements. They require their suppliers to anticipate this demand by constantly improving product performance. In the case of servo manufacturers, the need was for motors that could perform more complicated moves, produce higher torques and speeds. With the development of new micro electronic and magnet technology, servo manufacturers were increasing the capabilities of their motors. The market demanded a gearhead that would be able to match these requirements. The Stealth Helical Planetary Gearhead was designed for the needs of today's demanding servo applications. The idea behind Bayside's Stealth gearhead design is to accept high input speeds, deliver constant high output torque, exhibit high torsional stiffness and run quiet.

Gear Design Features

The Stealth is an all-helical planetary gearhead. Helical gearing has several attributes making it advantageous in planetary design, such as higher tooth contact ratio and greater face widths. As a result of this, helical gears are superior to straight spur gears in both load carrying capability and quietness during operation. Together with our advanced heat treating technology, superior gearhead design, and innovative mounting design, the Stealth is the most advanced gearhead on the market.

Our design engineers employed gear design software to optimize tooth geometry. The advanced design features that were developed through the use of this software were:

- Optimized recess approach action
- Lower sliding ratio
- Improved tooth contact pattern

Through software modification, these design improvements were incorporated into the Stealth. The advantages gained were:

- Higher tooth strength
- Increased efficiency
- Reduced noise
- Reduced heat

Helical vs. Straight Spur

In the case of spur gears, the line of contact is parallel to the axis. Helical teeth, which are skewed at an oblique angle to the axis, enter the meshing zone progressively, and therefore have a more gradual engagement than spur gear teeth. The contact line of the meshing teeth progresses diagonally across the face from the tip at one end to the root of the other, reducing vibration and noise. In addition, because the tooth engagement and load distribution is gradual, allowable speeds are greater for helical teeth than for spur gear teeth. This gradual loading of each tooth also reduces wear.

Moreover, the skewed oblique angle creates an extended length of the contact line, which results in a higher tooth contact ratio (between 2 and 3) and the load being distributed over a greater area. This allows helical gears to have superior load carrying capability compared to spur gears. Illustration (a) in Figure 1 shows a helical gear tooth contact line pattern compared to a straight spur tooth (illustration (b)).

Integral Ring Gear

All Stealth gearheads feature an integral ring gear, which is cut

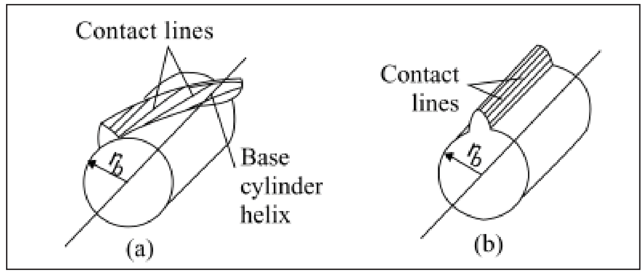

Figure 1 - Helical gear tooth contact pattern versus straight spur tooth.

directly into the main housing (Figure 2). This allows for larger gears and bearings in a similarly sized planetary gearhead where there is a separate ring gear and housing. Because of the larger sized ring gear, the center distance between the carrier and the planet gears in increased, reducing the tangential load seen by each tooth, greatly increasing the torque carrying capacity. In addition, a Stealth planet gear would be approximately 15% to 20% larger in diameter than a standard planetary gearhead. This translates to greater tooth thickness, and consequently higher torques.

Helicrown^R

To meet the performance of today's servo motors, the helical gear tooth needed to be enhanced. Bayside's engineers developed *Helicrown*^{R} . *Helicrown*^{R} combines the power of helical gears with the smooth, quiet engagement of tooth crowning and tip relief in an original way. Our engineers determined the optimum location to modify the entry and exit points of the gear tooth. This reduces gear noise without sacrificing strength. The maximum amount of contact still occurs across the face of the gear tooth but the tooth impact is lessened during tooth engagement. *Helicrown*^{R} provides a balance between torque, speed and noise in the gearhead. This gear tooth is 30 - 40% stronger than conventionally modified gears, coupled with quieter operation. The noise level for the overall gearhead does not exceed 68 dB.

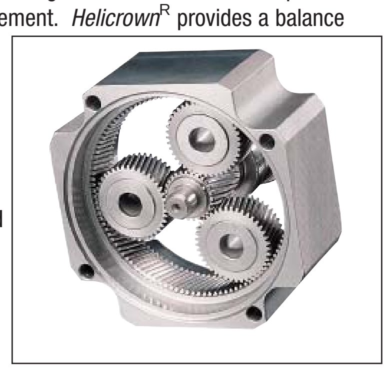

Figure 2 - Ring gear is cut directly into the main housing of a Stealth Planetary gearhead.

Plasma

Figure 3 - A unique characteristic of Bayside manufacturing capabilities is our in-house plasma nitriding equipment.

Nitriding

Plasma, or ion, nitriding is a method of surface hardening using an electrical discharge to introduce elemental nitrogen to the gear surface. In a vacuum, high voltage electrical energy is used to form a plasma, or process gas (a mixture of nitrogen and hydrogen). In the presence of this process gas, the load is maintained at a high DC potential with respect to the ion-nitriding vessel. Under the influence of this voltage, the nitrogen gas is dissociated and accelerated to impinge the workpiece, which acts as a cathode. Within a short distance of the workpiece, the positively charged nitrogen ion then acquires an electron from the cathode and emits a photon. The photon emission during the return of the nitrogen ions to their atomic state results in a visible glow (Figure 4). As the nitrogen concentration increases towards the surface, very fine precipitates are formed when the solubility limit of nitrogen is exceeded. These precipitates distort the lattice structure and thereby increase the hardness of the material. The nitriding current, temperature and process time determine the depth of the nitride case. By this process, the gear material's chemical composition can be precisely controlled. The advantages provided by this process are:

- Harder gear case hardness
- Improved control of case thickness and uniformity
- Lower part distortion
- Increased tensile strength of the surface of the gear.

A gear's life rate is directly related to the case hardness. The harder the gear surface, the longer the gear will survive before wearing. Typical gear manufacturers rate their gears for a hardness of approximately 55 Rc. Our plasma nitrided gears have a surface hardness greater than 62 Rc for excellent wear resistance, and consequently longer life.

In addition to hardness and wear resistance, the fatigue strength of the gear tooth is significantly increased. The formation of the precipitates on the case results in lattice expansion. The core, in order to maintain

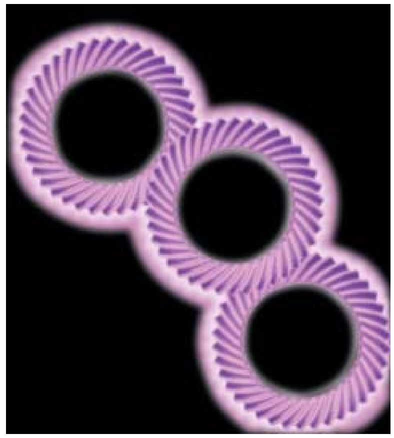

Figure 4 - Distinctive purple glow as a result of photon emission.

its original dimensions, keeps the nitrided case in compression. This compressive stress lowers the applied tensile stress on the material, increasing the fatigue strength.

Another feature of the plasma nitriding process is the gears inherent lubricity. During the latter phase of the heat treating cycle, the excess nitrides are diffused into the metal, leaving the "white layer". This layer is approximately 0.05 mm thick. The white layer composition formed on the gear provides natural lubricity. Also, the white layer is relatively inert, which provides for corrosion resistance in a variety of environments.

Plasma Nitriding versus Carburizing

Carburizing is the most widely used method of heat treating gears. The gear is placed in the furnace and heated above the critical, or transformation, range temperature. At this point free carbon is introduced into the furnace and is allowed to soak into the case of the gear material. Typically, a low carbon steel of 0.1% - 0.2% carbon is allowed to reach 0.8% - 0.9% range during the carburizing process, providing a soft core of 24 Rc. After achieving the desired case depth, the gear is quenched in a water or oil medium (The carbon content may sometimes go as high as 1.5%, but it is then tempered back to 0.8% - 0.9%). The case depth of the carburized gear is directly proportional to the time it is in the furnace and the temperature at which it is being soaked. The higher the temperature the faster the soaking and deeper the case, but the drawback of that is that quenching from a higher temperature may cause higher distortion. Small parts and fine pitch parts may be difficult to carburize, and a 55 Rc case may be the highest hardness attainable.

During carburizing the gear is red hot. Distortion is caused when the rate of cooling is uneven in the gear as the outside of the gear cools down faster than the inner part. In addition, the carburized case tends to be larger than before as additional carbon atoms are now embedded in the surface. The net result of this distortion is a tendency to end up with a slightly larger pressure angle and the helix angle tends to unwind. Also, the bore shrinks, the outside diameter becomes slightly coned and the part may develop radial and axial runout. For these reasons carburized parts may need post treatment processing such as grinding or hard hobbing with a carbide hob.

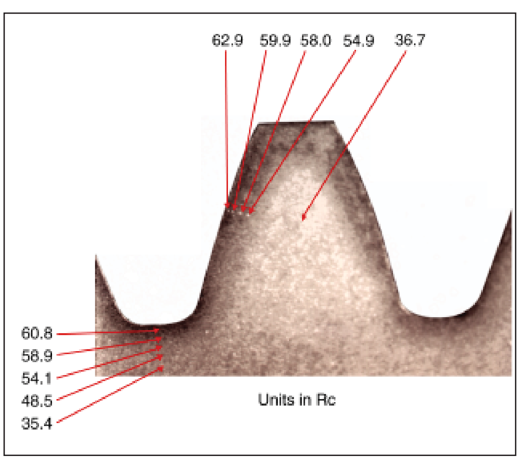

Figure 5 - Cross sectional view of a Stealth gear tooth showing hardness values after Plasma Nitriding.

Case depth is usually considered the depth to which the hardness is still above 50 rc. It is typically 75% - 90% of the total case. Case depth is a function of the pitch. In general, the coarser the pitch the deeper the case. Too deep a case will cause the teeth tips to become too brittle and possibly break. This condition is called case-core separation. Too thin a case will reduce teeth strength and cause premature pitting or lead to case crushing.

Unlike carburization, plasma nitrided gears require no rework. The ion nitriding process can be performed at relatively low temperatures, usually between 930 °F to 1,000 °F., way below the transformation temperature. The part is first drawn and tempered to relieve any internal stresses and brittleness, allowing the core to retain it's original hardness value of approximately 36 Rc. The ductile core exhibits very high shear strength, allowing the tooth to handle high shock loads. Due to the low temperature, as well as the gears being gas cooled after nitriding, there is no requirement for post-process machining, such as grinding, after treatment.

ServoMount™

Stealth Planetary gearheads employ Bayside's patented ServoMount™ integrated mounting kit. ServoMount™ features an integrated rear housing adapter and a balanced, pre-installed pinion. The pinion is mounted and supported in it's own "floating" bearing in the rear housing of the gearhead. The unique arrangement of the pinion bearing compensates for any motor shaft run-out or misalignments. ServoMount™ allows for error-free installation of Stealth planetary gearheads to any servo motor. This completely sealed design provides for optimum servo performance and longer life.

Floating the Pinion

Integrating the pinion gear into the gearhead requires a means of support and alignment, independent of the motor. Because the motor shaft is already constrained at two points by the motor bearings, adding another fixed bearing would create a condition of three rigid bearings in a line. Any amount of runout could result in significant stresses on the bearing elements, which could lead to premature bearing failure.

The solution developed by Bayside's engineers was to "float" the pinion bearing, so that it would compensate for shaft runout or misalignment. An elastomeric O-ring is mounted around a radial ball bearing. The O-ring supports and locates the pinion gear, but does not rigidly fix it. This feature allows for true gear alignment of the pinion, the benefits being:

- Allowable gearhead input speeds of 5,000 RPM
- Dampening of vibrations, extending gearhead life.
- Quieter operation

Clamp-on Pinion

The patented clamp-on pinion design used in the ServoMount™ is a single piece, balanced split collar pinion. The geared pinion is clamped over the motor shaft, allowing for easy, error-free assembly and small package size, resulting in higher system performance:

Low Inertia - The Clamp-on pinion's low mass and small diameter adds minimal inertia to the motor, resulting in less power waste and higher system performance.

High holding force - Split-collar clamps offer holding forces 5 to 25 times greater than the peak torque of most servo motors

Excellent concentricity - During production, the split collar is machined, then the pinion blank is clamped to a precision arbor for gear cutting. The result is excellent concentricity between motor shaft and gear teeth.

Ease of Assembly - Clamping devices with multiple screws require expertise to prevent misalignment. The Clamp-on pinion, with only one screw to tighten, requires no expertise or special tooling. Pre-installed, Clamp-on pinions eliminate the possibility of input misalignment.

Stealth Performance Features

Efficiency

The efficiency of a gearhead is the measurement of lost power transmitted through the gearhead. This is most often stated as a percentage of input power. Losses in power ultimately relate to heat generation, so it is important to maximize the efficiency. While it is common for both helical and spur gears to have high operating efficiencies (95% - 98%), the higher contact ratio of helical gears, along with the smooth rolling action, provides substantial benefit in increasing efficiency over that of spur gears. Given comparable operating conditions, helical gears are more efficient than spur gears.

While it is counter-intuitive for helical gears to have a higher efficiency than spur gears, there is clear operating evidence that supports the theory that a helical tooth geometry can be more efficient. The ultimate performance of a parallel axis gearhead assembly is dependent on factors such as; the accuracy of the gear teeth, the tooth profile, bearing selection, and lubrication characteristics. The Stealth Helical Planetary Gearhead was designed to optimize these factors.

In parallel axis gears there are several aspects of the gearhead that relate to efficiency losses. According to Dudley, in The Gear Handbook; "The overall efficiency of all gears is dependent on three separate and distinct types of losses. These three types are commonly known as (1) churning losses, (2) bearing losses, and (3) gear-mesh losses." Assuming the lubrication and bearing configurations are common between spur and helical, the primary issue to contend with is the gear-mesh.

Gear-mesh losses relate to the content of sliding versus rolling contact between the gear teeth which are directly related to the tooth profile and gearing technology. In gearheads that operate over a wide range of speeds and loads, it is important to utilize a tooth profile that reduces or eliminates sliding friction. Stealth's Helicrown tooth profile provides a distinct advantage in optimizing efficiency.

The first major benefits come directly from the operating principles of the helical gearing. These are:

1. The higher contact ratio reduces the tooth loading and shares the load over a greater surface area

2. The gradual tooth engagement allows the lubrication to remain on the teeth and leave a better film, minimizing the friction.

Secondly, the Stealth's *Helicrown*[R] incorporates a proprietary tooth modification of crowning and tip relief that facilitates a significantly higher percentage of rolling (versus sliding). In addition to the higher efficiency, the Stealth operates with lower noise and temperature, which are also a reflection of the tooth geometry. According to AGMA Gear Consultant, Ray Drago; "When two gear teeth with involute profiles are running together, there is one and only one contact position of those profiles where there is pure rolling action. That position is where the two profiles are in contact at the pitch point. As the contact moves towards or away from the pitch point, one profile slides over that of its mate. The amount of sliding increases in proportion to the distance from the pitch point". The *Helicrown*[R] profile is specifically designed to address this issue and minimize sliding.

While similar geometry could be generated, the Stealth has additional features which support higher efficiencies. Particularly, Plasma Nitriding as a heat treating method leaves a 'white layer' on the gear teeth that provides inherent lubricity to the gearing. In addition to the many benefits of plasma nitriding within the gearing performance, the white layer lets the teeth run more smoothly, reducing the coefficient of friction of the base materials. This results in less heat build up and higher operating efficiencies.

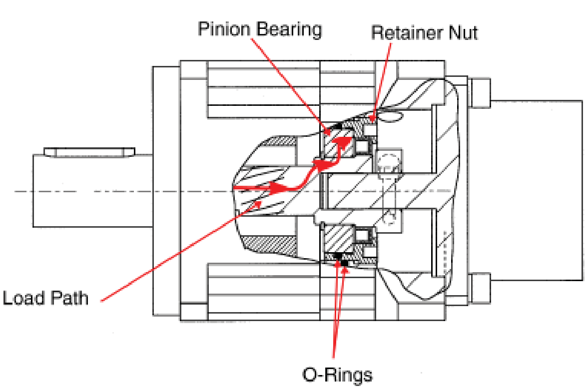

Figure 6 - This retainer nut design prevents axial motion from being transmitted to the motor.