Best Practices for Gearbox Assembly and Disassembly

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In most applications, gearbox reliability is critical to the productivity of the overall plant operation. So it follows that when industry is looking at the best ways to increase efficiency, reduce downtime, and increase profitability, gearbox performance and reliability are key factors.

Designing for repair, and writing effective repair procedures, can speed the service time, and provide a quality refurbishment. The best practices listed below are proven, effective methods used to install and remove bearings, seals, gears, couplings and shafts within a gearbox.

Introduction

When industry is looking at the best ways to increase efficiency, reduce downtime and increase profitability, gearbox performance and reliability are key factors. In most applications gearbox reliability is critical to the productivity of the overall plant operation. Repair is often required with a swift turnaround, as down time is very expensive. Designing for repair, and writing effective repair procedures, can speed the service time, and provide a quality refurbishment. Minimizing down time and extending service life will contribute significantly to achieving the lowest overall operation costs.

The best practices listed below are proven, effective methods used to install and remove bearings, seals, gears, couplings and shafts within a gearbox. These techniques are not new, and are usually obtained by hard-won experience. Collecting them in one location is an attempt to document the best practices and provide a reference for design engineers. Engineers write the procedures for assembly and disassembly, they also dictate to the rest of the design team the design intent. Including features to facilitate disassembly, minimizes repair cycle time and helps to prevent damage to components that could radically compromise their design life or performance.

Basic Types of Component and Assembly Interfaces

First we should examine the basic methods of attachments. Figures 1–4 illustrate some basic diagrams for the different types of common connections.

Components that have sustained damage in operation may not retain their original dimensions. The design intent of the fit will have to be determined to appropriately determine the values for the repaired component. There are technical documents for designing each of these types of fits. Please see the references for some of the relevant technical specifications for more detailed information.

Each of these interfaces can be made with different types of fits, clearance or interference. To determine which fit type you have, calculate the fit using Equation 1:

$$F = d - D \tag{1}$$

where:
F = maximum fit
d = smallest diameter of bore
D = the largest shaft diameter

Measure the bore and shaft at several locations, and use the smallest diameter bore and largest diameter shaft. If the shaft and bore tolerances are available, the entire expected fit range can be calculated. (To calculate the minimum fit, you would use the largest bore diameter minus the smallest shaft diameter.)

If this value is positive, the fit is clearance, if it is negative, the fit is interference. If the value is zero, the parts could theoretically slide together, but in practice a small amount of force or thermal difference is needed for assembly. The clearance value needed to slide parts together easily is generally assumed to be at least 0.001 inches. For long fits and large diameters, more clearance may be required; evaluating the tolerance and run-out of the parts will help determine an appropriate value.

Clearance fits. Clearance fits are used for easy assembly, in typically low speed applications. Set screws can be used to connect the shaft to the hub and transmit torque.

- Straight bore clearance fits slide together easily. There is no axial location control with this fit alone, and limited radial location. Shoulders, set screws and pins can be used to control axial locations.
- Splined connections fit multiple-tooth internal teeth against external teeth. There is clearance on both the sides and diameters of the teeth.
- Keyways transmit the torque between the shaft and hub. Parts assemble easily. Set screws can be used to fix the key and shaft in the bore.
- ***Interference fits***. When assembled, the bore expands and/or the shaft contracts so that the interface is in compression. Interference fits can transmit more torque than clearance fits. There are several different methods for assembly, which will be discussed later. These fits are typically used to control location of the components, axial and radial, as well as transmit torque. Interference fits are also used to maintain balance of components in high speed applications.
- ***Straight.*** A straight interface transmits torque while maintaining both axial and radial location control of the components.

- ***Tapered.*** A tapered shaft and bore under compression can be used to transmit the friction torque. The compression can be obtained by drawing the shafts together using a shaft nut or by thermal differential assembly.
- ***Keyways.*** Keys with interference fits do not shift and alter the balance of the components. They also can transmit more torque than a straight or tapered interface with the same interference, because the key helps ensure the joint will not slip.
- ***Splines.*** Usually these are interference fit on the outside diameter of the splines. These are typically used when radial position needs to be controlled.
- ***Bushings.*** There are various mechanical devices that can be used to create an interference fit. They slip on to the shaft with clearance, but when engaged create an interference fit between the shaft and hub. Tightening these devises is best done in a star pattern for proper centering of the parts. Centering is especially important if balance is critical. The best practice here is to follow the individual manufacturer's assembly instruction.
- ***Transition fits.*** Transition fits can be either clearance or interference. The tolerance range on the parts can result in a small interference or clearance based on the individual components. These fits are commonly used to ease assembly in applications that still require close fits. They can be assembled using the interference fit techniques but with much less force or temperature difference.
- ***Bearing fits.*** Bearing assembly is a special case. Bearings may be interference fit on one race of the bearing and clearance on the other. The mounting of the bearing on the shaft and in the housing will determine the operating clearance of the bearing. Having the correct bearing fit for the application is critical to achieving the design life and reliability of a bearing. Bearing catalogs have more information, or consult the manufacturers directly for each application.

Assembly Techniques

Thermal differential. Heating or cooling components can cause them to expand or contract to overcome interference and allow for easy assembly. The amount of temperature difference required can be calculated by using Equation 2 (use consistent units).

Thermal differential (simplified equation):

$$\Delta T = \frac{\delta}{\alpha\,(dia.)} \quad (2)$$

where:
δ = diametral interference
α = material coefficient of thermal expansion
dia = diameter in question

Most coefficients are given at a specific temperature, and will give a close enough approximation to the change in temperature for assembly purposes. Add a few thousands of an inch to the diametral interference to give a resulting clearance for assembly after the heat has expanded the parts.

It is common to add a few degrees to the delta to compensate for handling time and the assumptions of the equation. Rounding the value up by 20 degrees, or to an easy to measure value, is acceptable, as long as this does not put the value beyond the material limits. These material limits are based on composition and heat treatments. It is important not to exceed these limits as this could impact the ability of the component to function properly.

Because the temperature will change with time, it is important to have all the fixtures and tools for assembly prepared before removing the component from the oven or freezer. As for any job, proper personal protective equipment should be worn, as the parts will not be able to be touched by bare skin.

If there is a question about the temperature of the components or the measurement system, parts can be measured before assembly, at temperature, to determine they have reached the proper size. This must be done quickly because the delicate measurement instruments will be affected by the temperature too. It is easier to measure the temperature, but when developing a new process this technique can give valuable information.

Use Equation 2 to determine the amount of temperature difference required. The temperature differential can be obtained by heating, cooling or a combination of both.

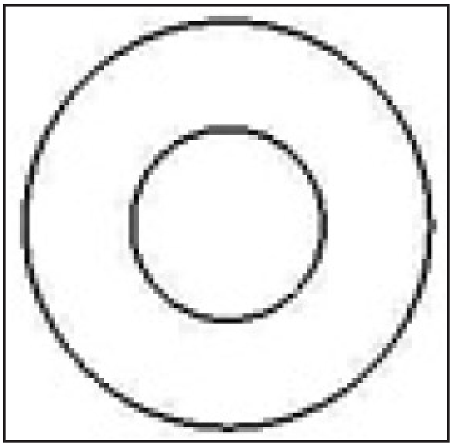

Figure 1 Straight bore.

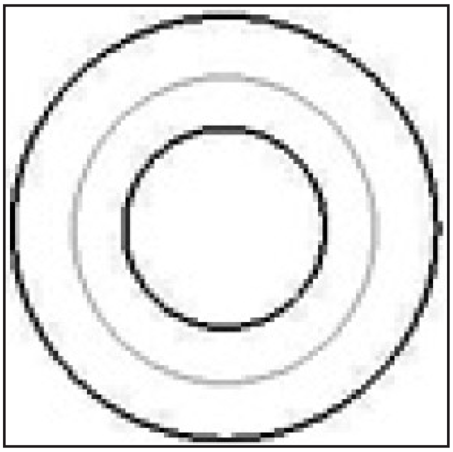

Figure 2 Tapered bore.

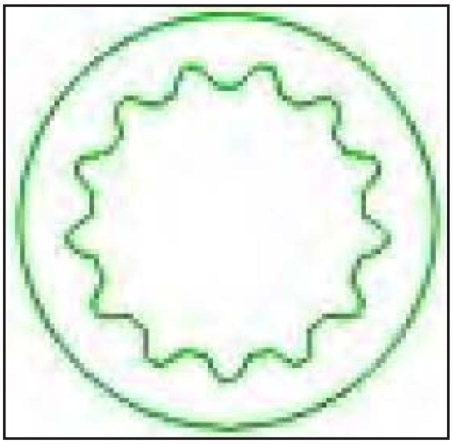

Figure 3 Splined bore.

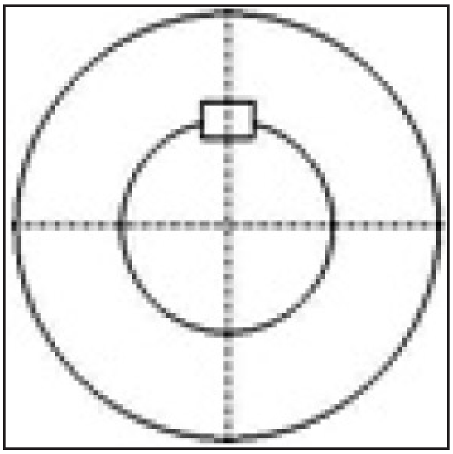

Figure 4 Keyed bore.

Lifting holes or fixtures for holding the components are especially important in thermal differential assembly. The fixtures need to be able to withstand the temperature, and also be out of the way for assembly. Planning the methods for lifting must be done before the components have changed temperature.

Having components level during assembly seems like a simple thing, but is often overlooked. It is easy to get components jammed if they are not aligned. Occasionally this can be overcome with gentle taps, but careful alignment can eliminate this need.

Components that have been assembled using heat or cold can creep apart as they cool. A bearing that is seated against a shoulder can move apart ever so slightly, and this can impact operation later. Clamping the parts or gently tapping a spacer down repeatedly as things normalize can prevent this. Never tap a bearing across the rollers. It is OK to gently tap an inner race seating on a shaft, or an outer race without rollers into the housing.

Heating. There are several methods of heating components: induction heaters, ovens, or hot oil baths. Thorough heating and consistent temperature is required. The best method is dependent mainly on economics and available resources.

Ovens make sense for large parts, high volume production, or for time savings. Many ovens can run unattended, so parts can be loaded at the end of a shift and heated overnight for assembly the next morning. This allows thorough heating and efficient use of time.

Induction heaters are fast and efficient. Load the part, press the button — and the heater runs. It monitors the temperature and shuts off when temperature is achieved. Most machines will monitor the temperature and reheat the part if the temperature drops more than five degrees.

Hot oil baths are a time-proven solution for heating parts. However, careful monitoring is required to prevent the oil from catching fire, and additional safety procedures must be observed to protect the operator from the hot oil.

No matter what the method, care must be taken to prevent overheating of the parts. There are various methods available such as, infrared thermometers, contact thermometers, or even temple sticks, (wax crayons that melt at a specific temperature).

Cooling. Cooling can be done with freezers, dry ice or liquid nitrogen. When using liquid nitrogen, use caution that freezing the components will not damage them. There are some heat treated components that should not be cryogenically treated.

There is always a chance of condensation forming on frozen parts. Wiping them down with isopropyl alcohol before assembly will help to dissipate the moisture. This should also be done as the parts return to ambient temperature if condensation appears.

Freezers are very convenient because parts can be placed in the freezer overnight and assembled in the morning.

Dry Ice can be packed around parts that need to be cooled. It is more difficult to get a consistent cooling of the parts due to it being solid. Use a thermometer to get an accurate temperature, realizing that it is a surface temperature. Parts may need to soak for a considerable time to be cooled through.

It is not often that both cooling and heating are required. This high amount of interference may better be obtained by pressing the parts together. There is a high risk of the parts cracking from thermal shock when heat and cold are both required.

Press. Parts can be pressed together using a mechanical or hydraulic press.

Caution must be taken when using a press, as the forces are very large and the process can be dangerous. As with all work, proper personal protective equipment and protective guarding around the equipment is recommended.

Basic equation. See Figure 5 for visual depiction of press fit.

$$F = A \mu P \tag{3}$$

$$A = \pi d L \tag{4}$$

$$P = \frac{\delta}{\left(\frac{d}{E_o}\right)\left(\frac{d_o^2 + d^2}{d_o^2 - d^2} + N_o\right) + \left(\frac{d}{E_i}\right)\left(\frac{d^2 + d_i^2}{d^2 - d_i^2} - N_i\right)} \tag{5}$$

where:

F = force to press

A = area of interface

μ = co-efficient of friction

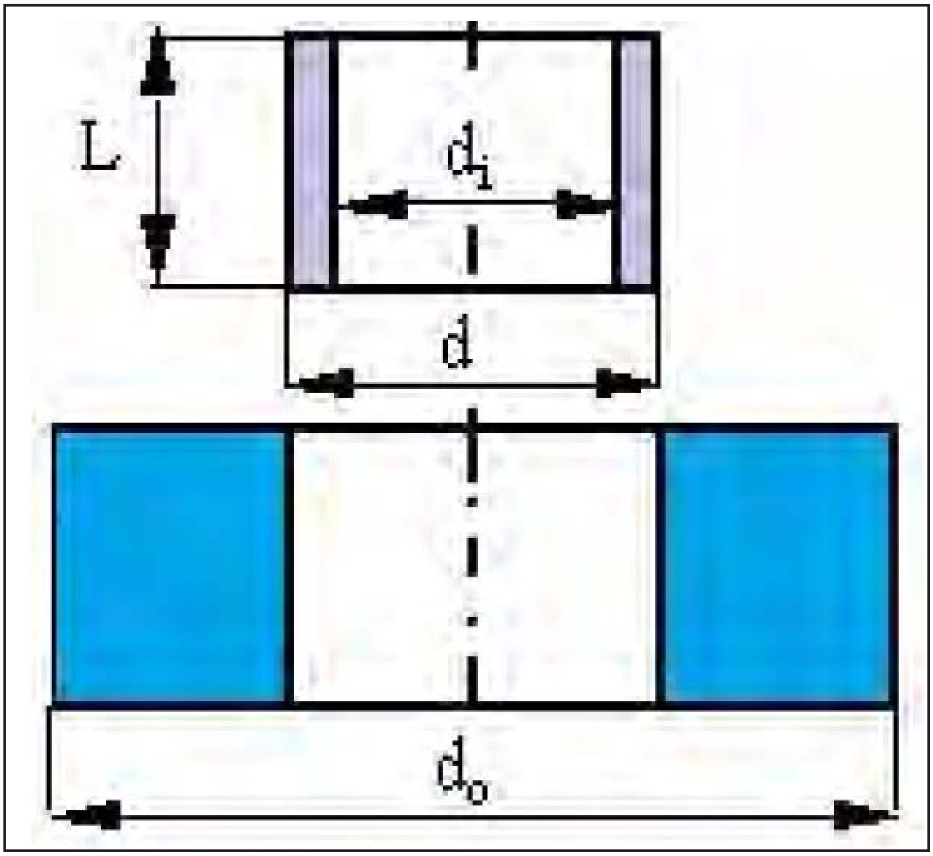

Figure 5 Press fit illustration.

P = interface pressure
D = shaft diameter/bore diameter (nominal)
L = length of fit
δ = diametral interference
d_o = hub outside diameter
d_i = bore in shaft or zero if solid shaft
E_o = Young's modulus of hub
E_i = Young's modulus of shaft
N_o = Poisson's ratio for the hub
N_i = Poisson's ratio for the shaft

The force calculated here is approximate and should be considered a minimum. It can be used to size the equipment needed. More force than calculated may be required if there is damage to the mating surfaces, or the parts are misaligned. Surface finish effects have not been considered in this calculation.

The first operation before pressing should be leveling the parts to avoid misalignment. This will help prevent galling the shaft, but not eliminate it.

There is always a significant risk of galling parts using a press. Using a lubricant like grease or anti seize will decrease the chances of galling but will also decrease the coefficient of friction and torque transmission capability of the joint. If the components are spacers and will not transmit torque, light lubricant is recommended. If the components are bearings or gears, lubricant is not recommended. A long lead-in chamfer should be added if possible. Consideration should be given to whether the joint will ever need to come apart again or not.

Shaft locknuts. Shaft nuts can be used to draw tapered shafts up and retain the compression. They can also be used to hold both straight and tapered connections together after other methods of assembly. They should always be used with some form of retention, such as a tab washer or set screws. This prevents them from backing off in service.

Hydraulic assist for keyless shafts. Many tapered shafts have features that allow assembly using a hydraulic pump system. Typically there is a tap in the shaft that oil can be pumped into. The oil dilates the bore. The hub is then pushed up the shaft until the required amount of advance is obtained. The pressure is released, completing the assembly.

The amount of advance determines the interference obtained (sometimes called draw-up).

Advance can be calculated using Equation 6:

$$A_d = \delta t \tag{6}$$

where:
A_d = advance
δ = diametral interference
t = shaft taper

Because the advance controls the fit and thus the torque capacity, controlling the advance during assembly is very important. Setting up stops and fixturing to stop the hub advance at the proper location is advised. Leveling the shaft before assembly is also recommended. These simple tips will make for a smoother assembly.

The hub is typically fitted with O-rings to retain the oil. The O-rings may also be located in both shaft and hub. The location of the assembly tap could also be located in the hub. Lightly lubricating the O-rings at assembly will help to keep the O-rings in their grooves while assembling and also help prevent rolling or pinching during assembly.

Bearing assembly. Bearing assembly is critical to reliability and performance of any gearbox. Most of the above mentioned techniques can be used to mount bearings. Because the bearings are precise mechanisms, special care must be taken when assembling.

Bearings must never be hammered into place. This can cause the rollers to exceed the material limits of the race and dent it. This bearing failure mechanism is called brinelling. This damage will propagate and ultimately fail the bearing much sooner than its expected design life.

If the correct fit of the bearings is not obtained, the life of the bearings will be impacted. If the fit is too tight, the bearing can be pinched and cause the gearbox to run hot, and the bearing could seize.

It is also possible if the fit is too loose for one or both of the races to spin. This will damage the shaft or housing and could generate debris that will damage itself and other bearings, gears and seals in the system.

Depending on the type of bearing and the application, the axial location of the bearing can also be critical to achieve its design life expectations. Bearings shimmed too tightly will run hot and can seize just like pinched bearings.

Seal assembly. There are many different types of seals on the market. Assemble per manufacturer's instructions for best results. If seals must be pressed into place, make sure to use a ring approximately the same diameter as the seal, but one that will not interfere with any rubber lips or other components. Apply even pressure over the entire surface, so the seal assembles level and does not get hung up anywhere.

If lip seals are used, lubricate the shaft that the lip will slide over to prevent nicks to the surface. Also be cautious of threads or keyways the seal may have to travel over. These may have to be wrapped in plastic wrap so the seal can slide over easily without damage.

Consider the location of the seal before determining when to assemble it. It may be easy to assemble a seal on a shaft before the shaft is placed into the next assembly, but the seal may be damaged during that assembly. It may be better to assemble at final assembly to prevent damage and the leaks that come with damaged seals.

Disassembly Techniques

Press. Using a mechanical or hydraulic press to separate parts is a very common practice. The same cautions for assembly also apply to disassembly, as the same large forces are involved. Presses come in a variety of sizes as well as vertical and horizontal versions. Make sure that the press is sized properly for the job you are attempting. Use a slow press speed, smoothly applying the load for best results.

If the interference is unknown, do a rough estimate by using the press calculation with 0.0015 inches per inch of diameter interference. This is a rule-of-thumb type number for a pressed-on fit. The rule of thumb for parts that have been assembled with the thermal differential method is interference of

0.0005 inches per inch of diametral interference. Apply a generous service factor to these calculations.

Higher fits than the rule-of-thumb fits are possible. It is also possible that the fit is galled, which will require additional force to remove. Make sure that the press equipment being used is adequately sized for safe operation.

Level the parts during setup to give an even press force on the shaft.

Rods similar in diameter to the shaft being pressed or other fixturing components are often necessary. In addition a method for catching the part that is being pressed out is also necessary. The parts will separate abruptly so this must be considered in advance.

Other techniques may need to be applied in addition to the press to release a very heavy press fit. Both thermal and hydraulic methods are commonly combined with press fits to remove large-diameter, heavy fits. Use caution when combining methods and consider operator safety.

Pullers. Pullers operate similarly to presses except the parts are pulled apart. There are both mechanical and hydraulic pullers. A jaw-type puller can be used anywhere you can get the jaws around the part. There are also bolt-on plates to extend the reach of the fingers. Designing in slots big enough for the jaws or shoulders wide enough to get puller jaws or plates behind makes disassembly faster and easier.

If slots or shoulders are not practical, taps of sufficient size can be located on the part and a puller similar to a wheel puller can be used. These pullers are constructed of high strength threaded rods and thick plates and are available with either hydraulic or mechanical jacks.

This method can also be used in combination with hydraulic and thermal techniques for stubborn fits. Always consider operator safety when combining methods.

Thermal differential. Heating or cooling the components for disassembly is difficult because the parts are physically connected and naturally want to reach the same temperature.

There are commercially available induction heaters for removal. They consist of either a coil or fixed diameter that wraps around the OD of the component to be removed. The heat must be applied very quickly so that the external part grows enough to release the fit before the internal component begins to grow also. This method is typically used in combination with a press. The heat expands the hub and much lower press force is required to remove the shaft.

It is possible to remove parts using gravity and a torch with a large diameter tip. This method must be monitored closely to make sure that the components are not heated beyond their temperature limits. Apply the heat to the outside of the part and keep the keep the heat moving so as not to overheat any one location. Closely monitor the temperatures of the components and discontinue attempts if too much of the heat is transferring into the shaft.

There is a real possibility that the component being heated may pass its thermal limit before removing. For this reason, this method is mostly used for removing parts that are being replaced, such as bearing races. Caution must be taken to make sure the part being reused is not damaged.

Hydraulic assist. Hydraulic removal of hubs works the same as assembly, except the location of the stop is different. There could also be no O-rings present if the hub was applied using heat. It is important to provide a stop for the hub to prevent it from being damaged. Once the hub is pressurized with oil, it will begin to slide down the taper. This may happen suddenly and with some force, so a fixture to stop the hub is advisable.

Hydraulic release may also be used in addition to a press in cases of extremely high fits. These may also appear on a straight bored shaft with a very heavy press fit.

Design Features to Assist Assembly/Disassembly

Frequently a component is designed by one team and another one assembles it, then yet another team does the repair. This can cause a lack of communication that can make assembly and repair more time consuming and thus costly than it could be. Adding small features to assist assembly or disassembly may add a small cost to the initial production but can save significant time, and therefore cost, in the future.

Lifting hole sizing. Size lifting holes not only for the weight of the part to be lifted, but also the weight of any additional components that could be added to the part. Also consider using these holes for removal of spacers and bearings. Size each lifting hole assuming it will be used vertically. This will give additional margin if the parts are rigged differently.

Even smaller components that could be lifted by hand can benefit from small threaded holes for lifting if the assembly is complicated or the parts must be lubricated at assembly. For instance, spacers that must be heated for assembly may be small enough to be lifted by hand, but assembly is much easier if there are taps so that the components can be picked up level and lowered easily on to a pre-leveled shaft.

Removal taps. Are taps located in the part so that bolts (sometimes called push bolts or jacking bolts) can be inserted to push two components apart?

Size and location of removal taps. Placement of removal taps in covers and spacers can prevent damaging these components at repair. Two extra taps on a bolt pattern can be used to release a pilot without damage or bending a flange. Always add taps that are sized to be able to take the loading to release the fit on the part. See the calculations above to see what the force is required to release the fit.

Caution must be used on the location of removal taps. It is possible to bend hubs with thin flanges or gear rims if the force from the puller rods is sufficient to overcome their strength. Keep taps as close to the diameter of the fit as possible. If these components are damaged at disassembly it will increase the cost of that repair. Damaging components can make repair of the gearbox as costly as buying a new replacement.

Hydraulic assist. If high torques and high interference fits are required, especially on tapered shafts, adding the taps for hydraulic assembly and disassembly is highly recommended. This process is very efficient when compared with other methods. When a procedure is followed, consistent results are obtainable.

Bushings. Designing in shaft connections with bushings is particularly important when assembly or disassembly of these components may need to be done in the field. Bushings are operated by a series of smaller bolts. They start as a clearance fit that the bolts draw up until the connection is made. This is the easiest shaft connection for the user to apply.

Bearing Location Features

There are many different kinds of bearings used in gearboxes. The individual designs have different requirements. Once the designs are determined, there are some key points to consider when working out the design.

Disassembly should also be considered when designing in shoulders and spacers for locating bearings. Taps in spacers or puller finger slots make assembling and disassembling bearings more efficient.

Some bearings do not require axial location by design, but are clamped with piloted covers to prevent the outer races from rotating during operation. Others require a preload or set axial location. Both of these can be accomplished with either a ground pilot on a cover or by shimming. The application usually guides which method is preferable. If there is a potential for multiple rebuilds or rebuilds in a remote location, shimming is usually preferred. If the rebuilds will always be done in a well-equipped facility, ground pilots are preferred. Please note that if shims are used, select the thicknesses such that the fewest number of shims is used and always sandwich the thinner shims within the thicker ones. Very thin shims can tear under load; the thicker ones on the outside give the pack more strength.

A method of preventing bearing outer races from spinning is to pin the outer races. This can be done by drilling a hole in a cover for a pin and chamfering a small slot in the outer race. Bearings can be ordered with this chamfer feature.

Alignment

Alignment can be another critical factor in establishing a good reassembly. Poor alignment of bores from side to side as well as the parallelism of mating shafts can cause a huge impact in the design life of gears and bearings as well as cause the gearbox to run hotter than it should. Any time a gearbox is refurbished, these alignments should be checked to insure a reliable rebuild. This is especially true if the bores require repair due to previous damage. Bringing the parallelism of the shafts back to design specifications is the difference between a refurbishment that will retain the reliability of the original design and one that will not.

Another issue that must be checked at refurbishment is parallelism of the mounting base to the internal shafting. If this is skewed when the gearbox is bolted into place, the case can flex and cause internal misalignment of the gears and shafts. This in turn can impact the life of the gearbox in service. It can easily be repaired by milling material off the bottom of the mounting feet. This repair helps to facilitate a better alignment when the gearbox is mounted in service.

(*It is recommended that the referenced specifications be reviewed in detail when used by the design engineer. A proper design requires more calculations than discussed in the scope of this paper.*)

Summary

- Basic principles of assembly and disassembly have been discussed above. None of these techniques are new. They are time-honored practices that have been passed down from person to person for years.
- This used to be accomplished through apprenticeships and mentoring. Most of those programs have fallen by the wayside.
- With this paper we are trying to collect that knowledge as a training tool for new design engineers, or as a convenient reference for engineers writing assembly or disassembly procedures.
- Adopting these procedures can make gearbox building and rebuilding more cost-effective while preserving reliability.

Ultimately, that is what all our customers — both internal and external — are looking for. **PTE**

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