Revised and updated 13 June 2023

Introduction

A hydraulically assisted power rack and pinion differs from a pitman-arm power steering gearbox in one very significant way: in the power steering box a piston applies hydraulic force on the *input* side of the gears, whereas in the power rack a piston applies hydraulic force on the *output* side. This important design feature largely relieves the rack and pinion gearset of the mechanical loads carried by the large, heavy gears in a power steering box, and allows the gears and their supporting structure to be made substantially smaller and lighter.

Hydraulically assisted power steering is a demand-based system. The work is performed by a pump, which, when commanded by a spring-centered servocontrol valve, pressurizes the working side of a piston *exactly enough to overcome the resistance.* The valve is forced open by a torque existing momentarily or continously in the steering column. This operating torque can result from the driver turning the steering wheel against the resistance of the front tires, or from the front tires attempting to turn the steering wheel against the resistance of the driver—the power assist does not distinguish between the two. In steering a race car, both conditions occur simultaneously.

The servo is an "open center" valve, which allows fluid to flow through it and return to the reservoir. As the valve orifices are angularly offset by steering torque, one directional channel is pressurized and the other exhausted. The pressure forces the steering in the appropriate direction at a rate dictated by the valve opening. Increased effort creates a wider opening and demands a proportionally greater response from the pump. As the steering resistance is overcome (or the steering wheel is released, which is the same condition) the torque decreases and the valve "catches up," springing back toward its centered or neutral position.

This process—the cycle of springing open and catching up—occurs within milliseconds and operates continuously during turning of the steering wheel against the resistance of the front tires (or, equally, resistance by the steering wheel against being turned by the front tires).

Analysis and Troubleshooting

1. "Pump catch" from insufficient flow

In hydraulic power steering, a dead spot or "catch" can occur in cases wherein:

(1a) The pump's fluid delivery is insufficient to *push the piston faster than the driver can move it with the steering wheel* (which is, essentially, the definition of power-assisted steering), or

(1b) The valve itself is incapable of the necessary flow rate. For reference, the flow capacity of a type CF rack is, at minimum, twice as much as that in an OEM steering, so case (1b) is highly unlikely.

Pump catch is commonly encountered during a quick and vigorous steering move or sequence of moves, such as countersteering in a loose condition or reversing direction for the second turn of an "S" bend. It is evidence that the pump cannot fill the cylinder quickly enough—in essence, the steering has suddenly outrun the flow, and is pulling the piston rather than being pushed by it. The condition is momentary and transient, and at slower speeds may appear to have been cured. The problem can be confirmed by attempting a violent move of the steering wheel with the car stationary. With a rack, most power steering defects can be revealed while parked because the rack is directly linked to the tires and the tires provide more turning resistance while stationary than while rolling.

2. "Pump catch" from tripping the relief valve

In order to overcome steering resistance, either momentary or continuous, the piston must be pushed with hydraulic pressure. As explained above, the required pressure is supplied by the pump in proportion to the demand from the servo. In US units, the pressure from the pump (in PSI) is multiplied by the area of the piston (in square inches) to create axial force on the rackshaft (in pounds-force). The available axial force can be found by measuring the maximum system pressure and doing the above calculation (e.g. 1,575 PSI x 1.63 in^2 = 2,567 lbf—in this example, about one and a quarter tons at the steering arm).

The maximum system pressure is limited by a safety or relief valve in the pump in order to protect it from breaking parts or bursting hoses—which it would attempt, if allowed to respond to the infinite resistance presented by the travel limit at full lock. At full lock, the relief valve opens, which puts the pump into a "bypass" mode where no additional force is possible. Using the above example, if the pump is found to go into relief at, for example, only 800 PSI, the maximum available axial force according to the formula would be 1,304 lbf, or about half strength at the steering arm. That may be enough to overcome the steering load in a given corner, or it may not.

The actual steering pressure requirement for a given track can be established with datalogging instrumentation. While the average load over a long-radius turn might not exceed 300 PSI, the sharpest corner on a road course could well demand, for example, a 1300 PSI spike. In that case, the pump's relief setting had better be at least 1400 PSI or there will be a risk of putting the system into relief while on the race track, which means *instantaneous* loss of pressure precisely at the instant it is most needed. Operating in relief incidentally creates tremendous waste heat, and will begin to damage the pump after about twenty seconds. For safety, the relief valve should always be set 100 PSI higher than the highest realistically expected demand. A pump's relief setting can be easily verified in a simple motorized test fixture using a pressure gauge and a shutoff valve.

3. Weak or no assist

(3a) Flow control piston is stuck: The small spring-loaded piston in the transverse bore of an automotive pump regulates the output flow by reacting to the momentary back pressure created by an RPM increase, and unmasking an internal return or "bypass" circuit. By responding rapidly and continuously it keeps the pump's output constant, at a rate controlled by the area of the pump's output orifice (e.g. 2.26 GPM, 3.11 GPM, etc). The rapid reciprocation of this piston in a bare aluminum bore can cause galling, which will roll up a burr like a snowball, wedging the piston ever closer to a fully-open position.

(3b) Field testing for stuck piston: With the internal bypass stuck open, fluid will be observed to return to the reservoir in the normal way *until the steering wheel is turned under load,* at which point the flow will stop. Removing the -6 output fitting from the pump will ordinarily allow the piston to pop out with it. If it remains stuck down in the bore, shown by the arrow in the picture above, the pump will not develop any working pressure. The piston will have to be extracted and the bore smoothed. On a new pump, hardcoat anodizing followed by honing the bore will prevent this problem.

(3c) Internal leakage in the rack or servo: Declining performance due to worn, shrunken and/or embrittled seals does not occur catastrophically; it develops over time. Leakage can be isolated with a known good pump and a flowmeter in the return line. When the pump goes into relief at full lock, all flow through the return should cease. In a quick-steering system, leakage below 0.2 GPM can be considered equivalent to zero as it will not be noticed as weak assist in the car. But—leakage greater than that means some or all the seals should be replaced at the next opportunity.

(3c.1) Chemical attack: Because the seals in the CF rack and servo are either Viton® fluorocarbon or PTFE/glass, they are not ordinarily vulnerable to attack by automotive fluids. They are rated for 168 hours' exposure to Dexron® III ATF @ 300°F. However, certain "synthetic" ATFs and power steering fluids contain highly aggressive chemicals and are best avoided. *Note: Dexron®IV is known to attack some Viton compounds.*

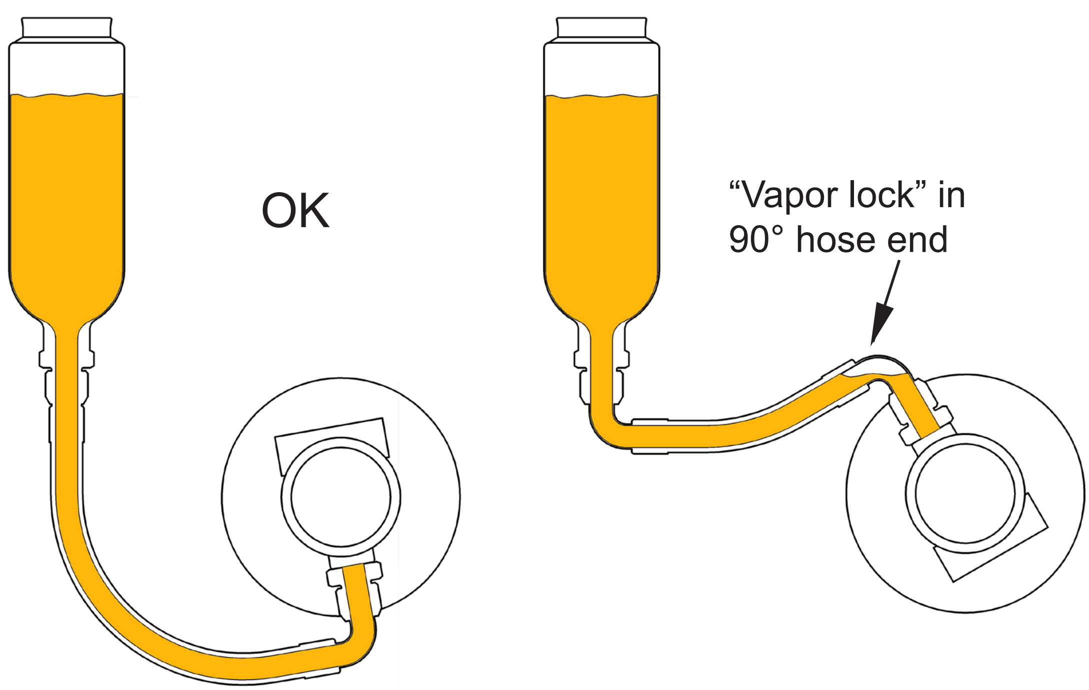
(3c.2) Heat: Chemical attack on elastomeric seals is accelerated by high heat. The temperature generated by the working pump will not ordinarily exceed the boiling point of water, and the rack, being largely aluminum, is an effective heat exchanger. However, in an enclosed space where outside air is excluded *(such as under the hood of a streamlined race car)* the steering can become a default heat exchanger for the engine. This can be combated with a cooler in the return line, provided it is positioned in positive airflow and has -8 ports. A cooler sized for -6 hose will be restrictive enough to cause back pressure, which is a further source of waste heat and, potentially, steering lag. Over time, heat will degrade any oil-compatible seal. If embrittlement of a fluorocarbon seal or O-ring is found, investigate the installation for possible contact with headers, and insulate accordingly.

Procedures for disassembly, reassembly and testing are covered under "Seal Replacement."

4. Intermittent, surging, or "lumpy" assist

If the steering wheel cannot be turned smoothly under load but exhibits "judder" (alternating segments of high resistance and release) the cause is usually a choked or starving pump intake. This can take several forms:

(4a) "Vapor lock" condition caused by an upwardly convex loop or bend in the intake hose, which leaves an air bubble to occupy part of the hose at that point—like the bubble in the glass vial of a carpenter's level. Its presence limits the flow of fluid to whatever cross-section of the hose remains open underneath the bubble. This causes the pump to alternately starve and recover. In many cases the element trapping air may be a 90° fitting, which is often discounted as a possible cause.



This condition is serious but can be corrected by rerouting the hose, inverting the pump, and/or repositioning the reservoir. Note that in the sketch the reservoir is elevated the same distance above the pump in both cases—enough to provide a good pressure head—but the plumbing on the right contains the fatal flaw.

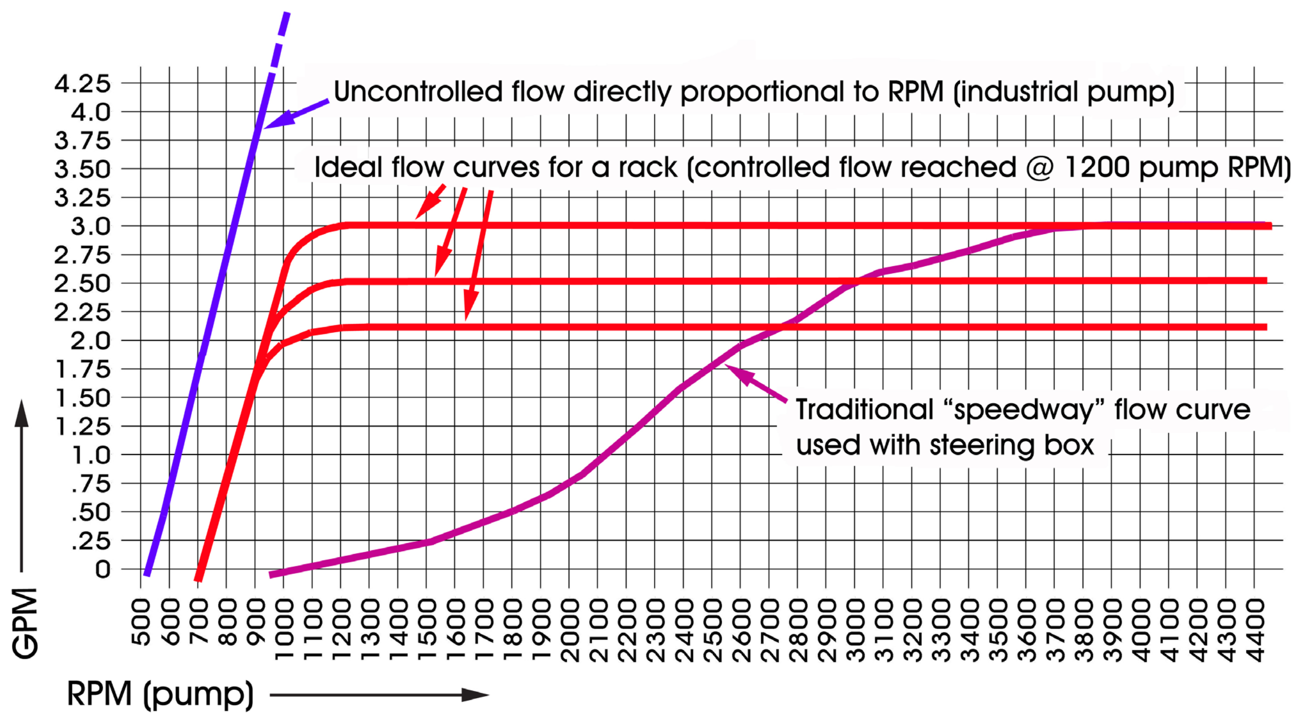
At racing speeds the trapped-air defect will cause cavitation, which will destroy the pump, which will spread hard steel particles through the circuit, which will in turn cause the servovalve to stick or seize.

Be aware that a plain horizontal run of hose also has the potential to starve the pump if it has even the slightest upward convexity.

(4b) Collapsing intake hose caused by inability to resist pump suction. The vacuum of a power steering pump is quite high, and the rubber-core stainless-braid hose commonly employed for dry-sump oiling systems will not resist it, especially as the fluid warms up and softens the hose. As the hose warms up it is gradually sucked shut, starving the pump and causing progressively harder steering until the assist is completely gone. The problem is frequently misdiagnosed because after cooling off, a reasonably new hose will have sprung back to its original shape and allowed the power steering to recover.

Unless there is an obvious kink or flat spot in the hose, the soft rubber liner will collapse without disturbing the outer stainless braid, and its collapsed condition will be invisible. The cure for this problem is to only use hose on the intake side that is rated for 26 in/Hg suction. Generally this means a rigid core such as PTFE.

(4c) Pump operating below its suction threshold, which on a vane-type automotive pump is about 700 pump RPM. Below that speed it won't provide power assist at all. Full power steering capability arrives as the pump reaches controlled flow. The flow rate and the RPM at which it is reached depend on the requirements for the car. For example, a street vehicle needs full steering assist available at engine idle or it will be impossible to parallel park. The steering rack in a race car, somewhat counterintuitively, has the same requirement for a constant fluid supply as the rack in a street vehicle—with the important exception that reduced assist at high speeds (a.k.a. "speed-sensitive steering") commonly engineered into street vehicles is obviously counterproductive on a race car.



In the past, speedway pumps have often been given increased internal relief so as to reduce the power tax on the engine below racing speeds. Since in a rack and pinion the hydraulic power is more directly and efficiently applied than in a steering box, its overall flow requirement is lower, *which reduces any power advantage that might be gained by crippling the assist.* Remember that the load-bearing elements in a rack and pinion are far smaller and lighter than those in a steering box, and a rack absolutely needs hydraulic power to shield these parts from exposure to direct steering loads (not to mention impacts). Maintaining fluid delivery at a rate that will adequately pressurize the rack piston at all times is essential unless the intent is to deliberately sacrifice it. *The consequences of operating the steering without sufficient oil pressure to lubricate the internal surfaces of the servovalve are pretty much the same as operating the engine without adequate oil pressure—except that the running clearance in the valve is about one-tenth that of the crankshaft, and its surfaces are hard and not embeddable like engine bearings.*

To correct insufficient suction, change the drive ratio of the pulleys and/or revise the pump profile so that “controlled flow” is reached closer to normal engine idle.

In all cases, steering the car while stationary with the engine off will accelerate wear on the valve and gear teeth (notably, this was the original reason for column locks on road cars). The best way to prevent this when the engine cannot be run is to (1) maneuver the car on casters or (2) connect a remote hydraulic power source.

(4d) Scored cylinder walls caused by pump debris. The piston seal is a Viton® O-ring with a large enough cross section to easily conform to a wavy or irregular surface, but both it and the piston can be embedded with hard steel particles which will eventually wear through even the 60Rc hardcoat-anodized cylinder wall. Once a score mark is deep enough that the O-ring cannot seal, *the steering pressure will drop as the piston passes the damaged section.* An additional effect is that the velocity of the fluid greatly increases as it is forced through the tiny orifice of the score mark. This creates waste heat, which rapidly accelerates the demise of the piston seal.

If the pump should come apart in a race, it should be assumed to have instantly distributed hard, sharp debris throughout the power steering system. The decision to continue the race without power assist, assuming it is within the physical capability of the driver, should be weighed against certain damage to—and possible writeoff of—the rack and servovalve.

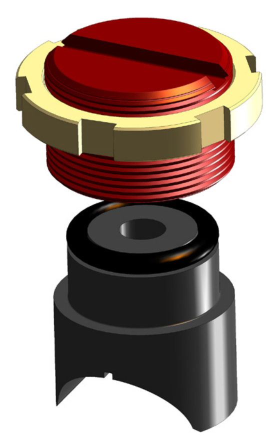
(4e) Vortex in the reservoir: this is relatively rare, but can occur where a tangential return stream, intended to centrifuge entrained air out of the fluid, is not separated from the suction outlet by a flow straightener. The spin of the fluid around the inside of the tank will build until a tapering column of air extends into the outlet (like a flushing toilet), interrupting the flow. The effect is more likely with higher-output pumps. In any case, a vortex is easily seen by looking into the reservoir with the pump turning at controlled-flow RPM, and countermeasures can be designed into the reservoir.

5. Vibration or “shimmy”

(5a) Mechanical causes include loose tie rod ends or excessive pinion backlash. The rack ends are adjustable, as is the pinion and the rack snubber. Checking these items is easy. If backlash is detected with the engine off, *confirm the diagnosis by starting the engine* rather than assuming a loose pinion. At pressures over 65 PSI the rack becomes backlash-neutral and will react to very low resistance including seal drag. Normally, as soon as the engine is started any backlash detected while parked will instantly disappear.

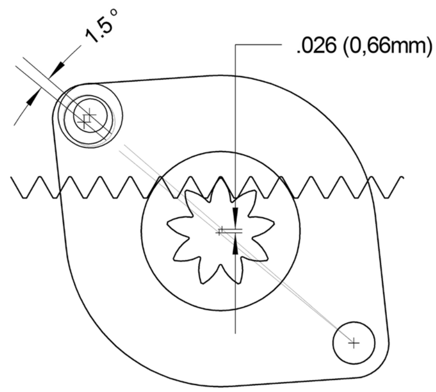
(5a.1) Rack end adjustment: Play in the monoball rack ends is easily identified, and easily adjusted with a pair of hook-type spanner wrenches (available as service tools) for whatever degree of freedom is preferred by the race engineer or mechanic. A cutaway view of the monoball is shown under “Race Preparation.”

(5a.2) Snubber adjustment: The gear teeth have a 30° pressure angle, which generates a higher separating force than the 20° pressure angle used in industrial gearing. Note that the snubber is not a backlash preloader like in an OEM rack, but is a **backstop** to prevent the rackshaft from being forced away from the pinion. It is cushioned by a spring or an O-ring (shown at right).



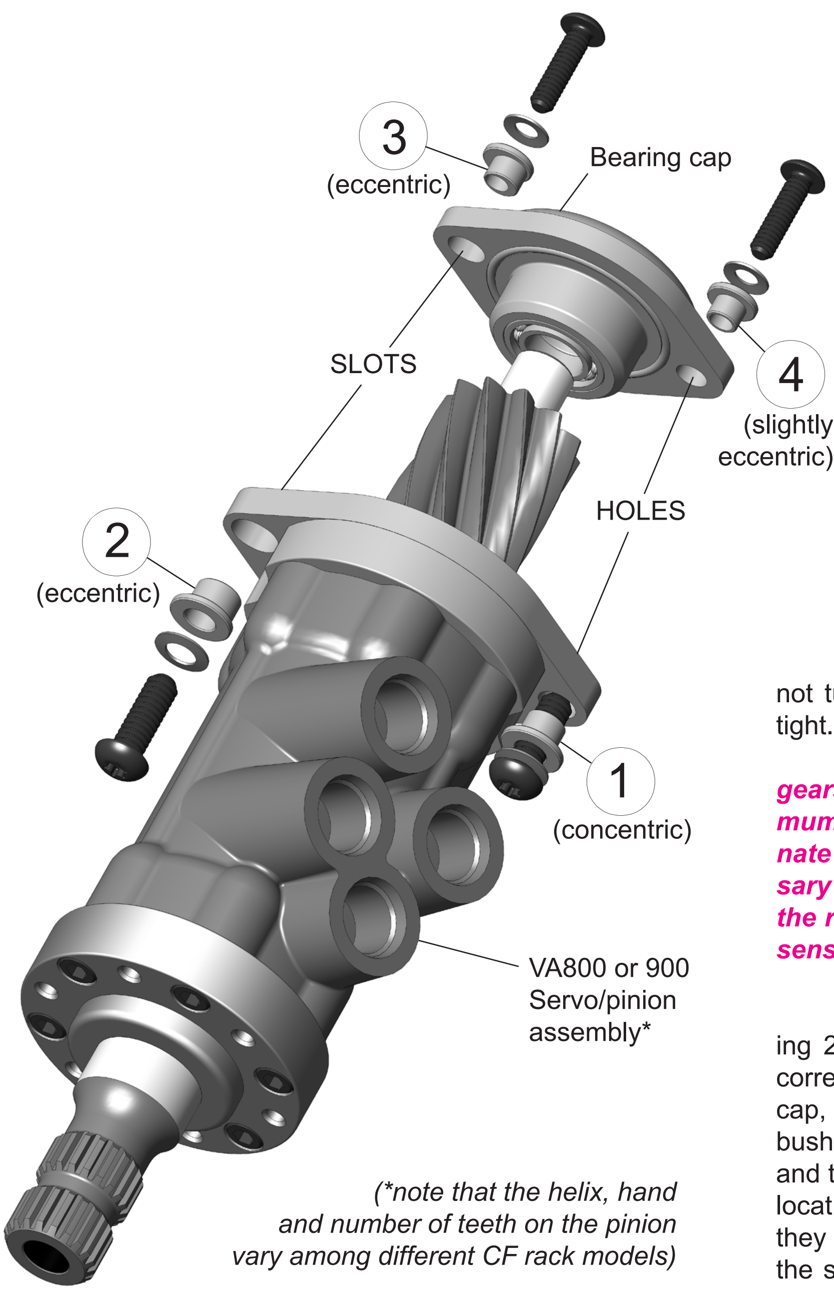
Rack bushing wear will eventually result in apparent play at the pinion, which is compensated for to some degree by residual pressure of the snubber. To reset the snubber, break loose the locking nut (using the same M600 tool used on the monoball rack ends) and turn the screw with any convenient item that will fit in the slot. While this is being done, turn the steering wheel back and forth to (1) verify removal of the play, and (2) guard against overtightening, which will act as a brake on the rack. Start the engine. ***If the play cannot be removed by this procedure without overtightening, back out the snubber and reset the pinion backlash.***

(5a.3) Pinion adjustment: The backlash between the pinion and rack teeth is set by simply swinging the pinion in an arc and locking it in place. As shown at right, the main servo/pinion flange pivots about a screw (which is piloted in a concentric steel bushing to prevent wear of the aluminum flange). When the pinion is felt to have the desired contact, the angular position of the flange is locked by starting the second screw and rotating its eccentric bushing until it will go into the slot. Once the second screw is installed the pinion axis cannot be moved. To make any further change in the adjustment the second screw and the eccentric must be removed.



For reference, the 1.5° total arc of movement translates to about .026 at the pitch line of the rack.

To adjust the backlash, the eccentric bushings 3 and 4 must be removed ***and the snubber backed out so that it cannot exert any pressure against the rackshaft.*** Next, remove eccentric bushing 2. Leave concentric bushing 1 in place with its screw loosened.



*(*note that the helix, hand and number of teeth on the pinion vary among different CF rack models)*

By hand, swing the pinion into mesh with the rack. While pushing the two together, twist the rackshaft back and forth to establish its alignment with the pinion teeth. When the gear contact is snug enough that the rackshaft cannot be twisted with respect to the pinion, tighten the screw in concentric bushing 1. This will hold the pinion in position for testing.

Turn the input shaft lightly back and forth to verify that the backlash has been removed or minimized.

When the desired position has been found, start the second screw, rotating its eccentric bushing until it will enter the slot. Tighten the screws in both 1 and 2 and test the backlash by turning the pinion. If at this point the pinion does not turn easily and smoothly, it is adjusted too tight.

The purpose of backlash in a pair of gears is to allow them to operate with minimum friction. While it is desirable to eliminate backlash in the steering, it is not necessary to force the pinion into preload against the rack teeth; if the gears are preloaded the sensitivity of the steering will be reduced.

If it is too tight, remove eccentric bushing 2 and repeat the procedure. When it feels correct, reinstall bushings 3 and 4 in the bearing cap, making absolutely certain that the slot for bushing 3 is aligned with the slot for bushing 2, and that the bushings are installed in the correct locations according to the drawing. Otherwise, they cannot be rotated into a position where the screws will start. **Forcing will damage the parts.**

Installing the bearing cap and tightening all the screws should not affect your adjustment. If it makes the pinion too tight, you used too much force when holding the pinion against the rack. Simply loosen the screws, take out the eccentric bushings and repeat the exercise. Lastly, bring the snubber into contact. ***Note that the snubber is a backstop, like that used against the ring gear in a rear end. It's not a backlash adjuster.***

(5a.4) Wornout rack bushings: While resetting the backlash will compensate to some extent for loose rack bushings, it is by no means a permanent fix. Bronze bushings support the rackshaft for a total length (depending on the model) of up to 5 rack diameters, and the rackshaft is hard chromed, but even this combination can wear over time. A good test for bushing wear is to extend the shaft to full lock (particularly toward the side with the teeth) and force it up and down against a dial indicator. More than .008 movement means the bushings should be replaced. Replacing the bushings is covered later in this manual but is well outside the scope of trackside trouble-shooting.

(5b) Hydraulic causes include air entrained in the fluid. Unlike liquids, air is compressible and its power transmission is not positive. In a power steering rack, the principal trap for air is the cylinder.

(5b.1) Introduction of air: Air is unavoidably introduced as lines are uncapped and reconnected, e.g. when changing engines. In the reservoir, a turbulent or splashing return stream will continually mix air into the fluid. Make sure that (1) returning fluid enters far enough below the level in the tank that it cannot disturb the surface, and (2) that it is far enough above the suction outlet that entrained air will not be recirculated by the pump. Note that because a power rack is more directly connected to the front wheels than a steering box, aerated fluid will be more directly apparent.

(5b.2) Bleeding: Prior to initial startup (or after replacement of any part of the fluid circuit) the steering should be cycled through its full stroke with the wheels off the ground, while listening for air bubbles squirting back into the tank through the return line. It is not necessary to turn the steering wheel; the rack's fluid circuit has a very free exhaust and the steering can be cycled lock to lock by grasping a tire (this is also an excellent method for detecting a bind or other mechanical problem in the rack). The escape route for air is through the left and right hoses into the return channel of the servovalve. Slowly reciprocating the rack piston left to right repeatedly will expel air alternately through the left and right hoses. Keep in mind that *as the rack reaches the end of its travel and the direction is reversed, any aerated fluid that has not reached the servovalve will be sucked back into the cylinder*—so some patience is required. On the type CF rack the cylinder ports are, whenever possible, located at or near the 12 o'clock position, so the cylinder is to a large extent self-bleeding. Nextgen racks incorporating the Big Bore cylinder have their main ports are rotated forward to allow bleeder screws at the 12 o'clock position.

When no more air can be heard, the system can be considered fully bled and the engine can be started. Caution: thick, syrupy fluids advertised as "non foaming" may be self-defeating in that they tend to keep air bubbles in suspension longer. The reservoir should be vented to atmosphere rather than sealed, or it will become a pressure cooker. In a correctly vented tank, there should be some foam visible, at least initially. Foam is evidence that air is escaping from the oil. Except in the case of a very long hydraulic circuit, such as a mid-engined car with an engine-driven pump, bleeding with a standard automotive-service vacuum device will also work.

5. Wandering steering lacking positive return to center

(5a) Loose torsion bar screw: Power steering, like all human-operated hydraulic systems, uses spring loading (in this case a torsion bar) to return its control valve to a neutral or centered position. Opening of the valve requires applying torque against the resistance of the torsion bar: **a heavier bar means heavier steering and a lighter bar means lighter steering.** Any free play in the torsion bar allows the valve to open without resistance over the angular offset amount allowed by the free play. *Free play is equivalent to an infinitely light torsion bar,* so the steering will drift in whatever direction the play is momentarily being taken up by the steering wheel. Since the valve is highly sensitive, a few thousandths' play will be immediately noticed as a tendency to overcorrect. The experience of driving a race car with a loose torsion bar has been described as resembling a very bad video game.

To prevent loosening from vibration, a locking ring is provided, with a second pair of set screws bearing against the adjustment screws. The outer set screws have a finer pitch than the inner set screws which stops them from being backed out by the inner screws. If the locking ring has been left off, the only thing retaining the inner screws other than their tightening torque is blue Loctite® (#242 or #243). While this is ordinarily sufficient for a short track event, it should not be relied upon alone for retention during an endurance event. The locking collar has proven absolutely reliable over 24-hour races and should not be left off. Reinstall it each time an adjustment is made to the directional bias. Refer to pages 11 and 12 for illustrations.

(5b) Worn drive bolt slot in the spool: A loose drive bolt slot can sometimes result from high-frequency hammering caused by driving on serrated curbs, especially when the valve is too stiff to provide enough response. *If the hammering is being transferred through to the driver's hands, it may be safely assumed that the valve is too stiff and damage will result.* The spool slot is not ordinarily something that can be addressed trackside, but if time permits, another complete servo/pinion assembly can easily be substituted, followed by bleeding. Note that wildly oscillating steering which occurs at the same point on the track (such as a transition from flat road course to high-banked oval) can be suppressed with a restrictor in the servo return port. This will add extra damping to the steering in cases where it is not practical to simply increase the assist response with a lighter T-bar.

The spool is furnished with two slots. During a rebuild, turning the spool 180° and using the other slot will restore the original light press fit and cure the problem. *Consideration should be given to using the next lighter torsion bar or adding a V180-8 restrictor.*

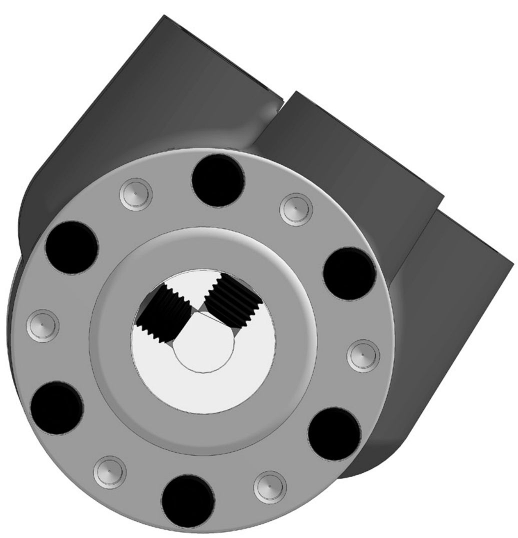
(5c) Spool jammed by grit: Wear particles (or pump debris as mentioned in **3d** above), forced into the interface between the valve input shaft and the spool, will interfere with the free return of the valve to its neutral or open center position. Another cause is galling and seizure from dry operation under load—a consequence of finishing a race with a blown pump, *or* using the steering wheel to maneuver the car in the garage without the engine running. As in **4c**, use a trolley jack or tire dollies to prevent dry wear in the valve.

Race Preparation

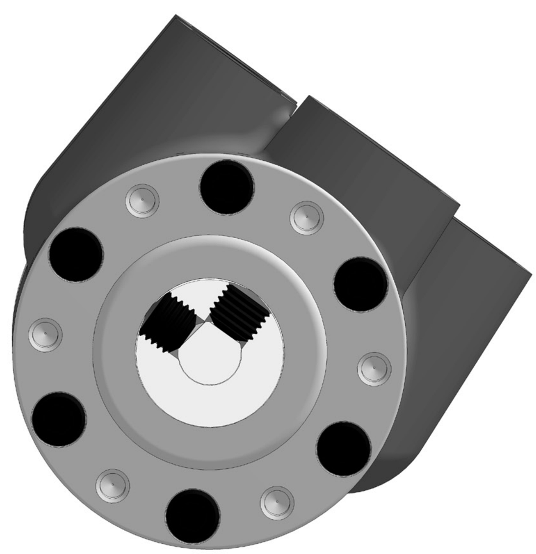
1. Setting the steering centered or with a directional bias

Centering: The directional bias can be centered with the set screws on the input shaft either on a test rig or in the car. To adjust in the car, first get the front wheels off the ground. Start the engine and observe which way the front wheels drift. If the pump is of the type that requires race RPM in order to work, speed up the engine until drift can be seen. If the steering will not favor one way over another, then the valve can be considered balanced. To make certain, flick the steering wheel and try to make it coast. Referring to the cutaway illustration below, correct a *rightward* drift by tightening the *right* set screw, and a *leftward* drift by tightening the *left* set screw. Note that both screws bear against their respective ramps on the torsion bar, so **in order to tighten the left screw, one must first loosen the right, and vice versa.**

CAUTION—RISK OF PERSONAL INJURY:
NEVER PUT A HEX KEY IN THE SCREWS WITH THE ENGINE RUNNING!



Biased 100% to the RIGHT
(will drift hard right)



Biased 100% to the LEFT
(will drift hard left)

Note that the adjustment is sensitive. One-twelfth of a turn—the distance between numbers on a clock face—will make a difference. The quickest way to master the procedure is to simply make a gross adjustment (such as a quarter turn), start the engine, and observe the results. Then make a similar adjustment in the opposite direction. After that it will be relatively easy to narrow down the neutral position and set it.

With the wheels back on the ground and the car rolling, any drift will be directly proportional to whatever caster/camber split or other asymmetrical geometry is being used for that particular track.

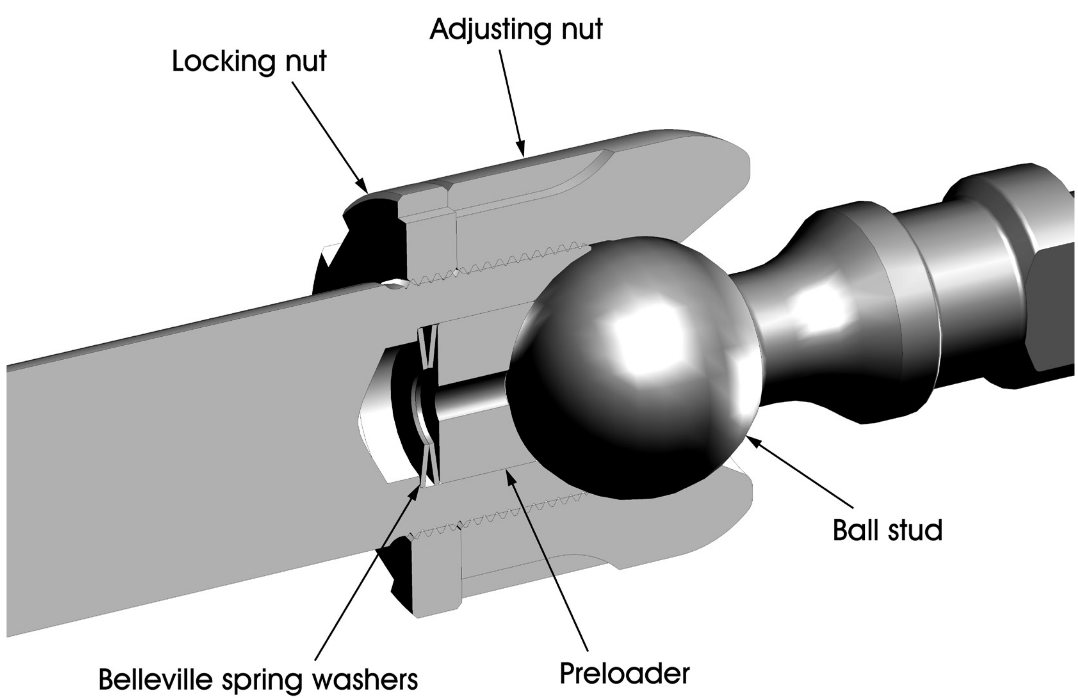
Setting a deliberate bias: In the event that a pronounced pull toward the infield from split or staggered caster interferes with the driver's control, the directional bias can easily be set to countersteer by enough to partially or completely neutralize the unequal muscle load on the driver. This effect is created *at the steering wheel,* without in any way affecting the steering geometry, the weight and balance of the race car, or the diagonal jacking effect of positive caster.

An important effect of adjusting the bias for a high-banked race track is that it will change the clock position of the driver's hands when holding the car in a turn, giving the same effect as a slower steering ratio but without sacrificing the ability to react quickly.

Loctite® 243 (the oil-compatible version of 242) can be applied to the screws before the final setting. Another option is to apply Loctite® 290 penetrating threadlocker after completing the setting, but be extremely careful not to spill any on the input shaft, as it will run down into the shaft seals. The torsion bar has an O-ring to isolate fluid from the set screws and prevent spiral leakage up the threads, so use of a sealant on the threads (such as Loctite® 565, Aviation Permatex® in a brush-top can, etc.) is optional. Note that sealant will prevent Loctite® 243 from being effective at locking the screws. After finalizing an adjustment, make absolutely sure to install the locking ring over the set screws (pictured on pp. 11-12)

2. Adjusting the monoball rack ends

Preload: The inner tie rod ends are adjustable for whatever degree of freedom is preferred by the race engineer or mechanic. The ball studs are preloaded by a bronze follower which is backed up by a stack of Belleville spring washers. The Belleville washers are spring-tempered steel and are available in two thicknesses, .022 and .032. They may be used in any combination to provide the desired total compression force. In all cases they must be installed with their **convex sides back to back** as shown below.



Do not stack the spring washers high enough to break them. With about .005 protrusion of the bronze follower into the spherical cavity it should be possible to completely lock up the ball joint with very little effort beyond hand tight, which means the ball stud will have solid support under compression or hammering. An excessive spring stack adds nothing, and can result in cracking the spring washers.

Avoid overfilling the spherical cavity with grease, as it will compress trapped air and create a false "spring" effect. It should always be possible to lock any movement of the ball by simply tightening the adjusting nut by hand. If you can't positively lock it, back it off and release the trapped air.

Loosening and tightening: The large adjusting nut with the internal spherical race has six notches and the locking nut has seven, for engaging the M600 hook-type spanner wrenches. There will always be one position that will allow two opposing wrenches to be aligned for convenient squeezing together with one hand by a mechanic of average strength, which will lock the adjustment. The thread is an extra-fine 1-20 pitch, which at a given torque develops a much greater tightening force than the standard 1-12 fine thread. The precision class 3 threads will allow easy removal, installation, and sensitive preload adjustment *by hand* if not abused (e.g. tightened with a cheater pipe on the wrenches).

Lubricant should be used on the threads, such as grease or engine oil. If you use anti-seize compound, test it first for particle size. If the solid content can be detected between your fingertips, do not use it. Note that some "anti-seize" compounds made for use in oilfield and mining applications contain coarse, hard nickel spheres, which in anything smaller than drill pipe are the equivalent of gravel and will seize the thread and scrap the rackshaft.

NEVER use a single wrench on the rackshaft, expecting the pinion to prevent rotation—always use two wrenches against each other.

3. Lubrication

Rack grease: The sleeve bearings in the left end of the housing are lubricated by the greased rackshaft. The rackshaft and its teeth should ideally be coated with a heavy (i.e., NLGI 2.5 weight, if available) lithium grease containing 5% MoS_2. Since the main idea is simply *lubrication of the moving parts* there is nothing wrong with using your favorite grease—except that silicone grease (used in submersible boat-trailer wheel bearings) should not be used on steel sliding surfaces.

The rack housing contains an internal wiper to prevent rack grease from getting under the cylinder rod seal when turning right.

Oil: The sleeve bearings at the inner and outer ends of the cylinder are lubricated by the pressurized power steering fluid. The right end of the cylinder has a wiper to exclude rack grease from the rod seal when turning left.

Monoball grease: Using the same Lithium/Moly (or equivalent) grease as on the rackshaft, cover the spherical joint area on both rack ends. Grease the inside of both rack boots to provide a reserve.

Power steering fluids: Acceptable fluids for use in a Woodward rack are: Dexron® III ATF, NAPA p/n 9801 petroleum (oil) type power steering fluid, AW32 hydraulic oil, and, in Europe, Pentosin® CH-11S. If none of these are readily available, the internal passages in both rack and servovalve are easily large enough to flow higher-viscosity fluids such as AW46 hydraulic oil, MIL-L-2104, 5W-40 or 10W-40 motor oil without problems. Dexron®IV is destructive to some Viton® compounds and should not be used.

Evaluating an unlisted fluid: Advertising claims notwithstanding, there is no *functional* difference among various brands of hydraulic fluid when used in a CF rack. The power steering oil must, like any liquid, be practically incompressible, must flow rapidly enough to operate the steering (note that while fluid viscosity is critical in many OEM racks with small porting and lines as small as -3, it is largely irrelevant in a CF), must lubricate the pump and the moving parts in the rack) and, finally, must not attack the seals.

Some performance aftermarket brands of "synthetic" ATF or PS fluid contain aggressive chemicals which tend to embrittle elastomeric seals, especially when accelerated by heat, so we cannot at this time recommend any outside the parts list. For anyone wishing to evaluate the compatibility of a fluid not listed above, we suggest the following testing procedure:

1. Carefully measure and record the inner outer, and cross-sectional dimensions of an unused set of seals and their durometer hardness. *Elongation* is a commonly cited property of elastomers, but that testing is normally performed on prepared shapes of raw stock. It is practically impossible to measure directly from a molded seal. However, it *is* inversely proportional to hardness, so the relative elongation can be imputed from that.

2. Using a (used) crock pot or similar vessel, in an area adequately secured against fire, cook them in your test fluid at 300° F. (150° C.) continuously for 7 days.

3. Measure and record their dimensions and hardness. For reference, if the hardness of the seals has not increased by more than 2 Shore A points and/or the dimensions have not shrunk by more than 1%, the fluid can be considered compatible.

4. Rack installation

Mounting clamps: When bolting the rack onto the chassis brackets, make sure their surfaces lie in the same plane. The steering rack is quite robust, but *only in the direction it is used.* It is not a frame crossmember, and is definitely not capable of forcing welded mounting surfaces into alignment.

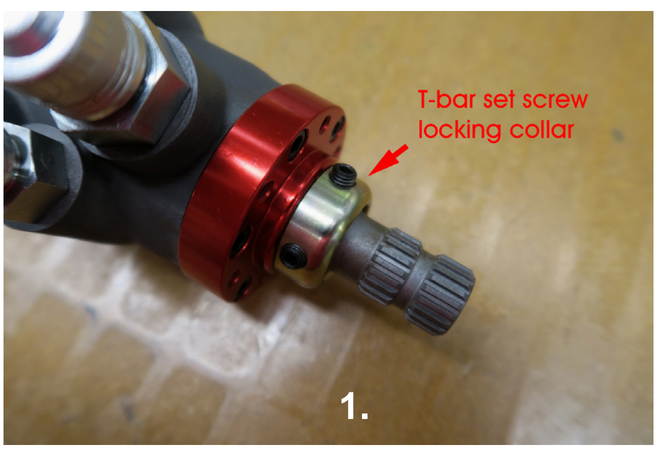
The mounting brackets on the Nextgen chassis are a minimum of 25.488 apart, and the corresponding rack width between shoulders is 25.488 to 25.458, which guarantees that any production rack can be installed into any production chassis. The chassis design additionally assumed a 1mm (.040) shim allowance to absorb any excessive clearance. Note that *shims used between the rack housing and cylinder as a means of clocking the cylinder ports* may result in exceeding the length tolerance and will require facing the housing or cylinder shoulder.

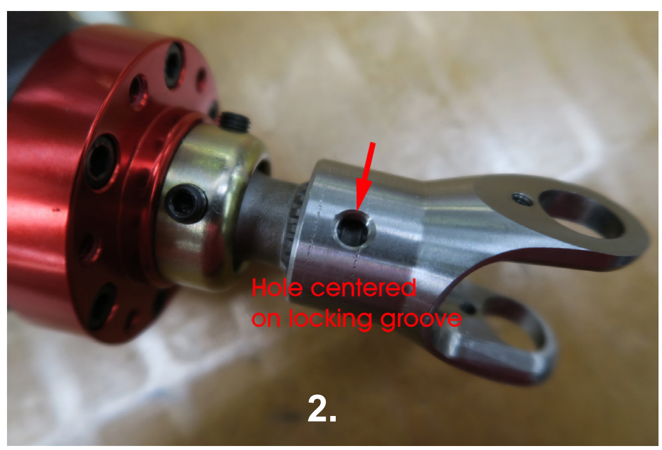
The mounting clamps use either 5/16 or M8 fasteners. The split part of the clamp normally has two aluminum shim washers of the correct thickness to allow the two halves to seat together solidly, so that the fasteners can develop full clamping tension—and a secure grip on the steering rack—without stretching the clamp material. Also, the clamps are a slight interference fit on the rack housing diameter. To increase or restore the clamping force, file .001 at a time from the cap or from one or both shim washers.

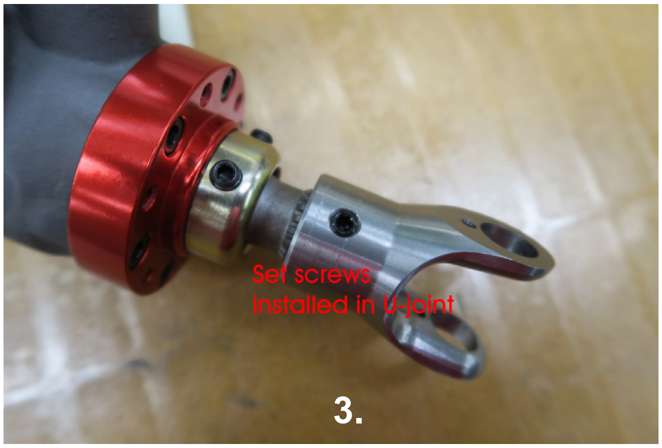
While tightening the clamps, turn the rack back and forth and be alert for any binding. If the rack movement should become stiff at any point, determine which bolt must be loosened to release the bind and correct the misalignment by scraping or filing any built-up powder coat or other obstruction from the mounting pad on the chassis. In some cases, such as distortion due to a crash, it may be necessary to use shim stock. If you have to shim it, try no more than .005 at a time. Continue until free movement is obtained with both clamps fully tightened.

U-joint connection: The input spline is machined with a locking groove whose sides are shaped to create a wedging action through positive interference with the knurled cup point of the 1/4-28 set screws in a Woodward U-joint. The spline profile is nearly square, which provides an interlocking grip without the cam-out tendency of 45° serrations. If Loctite® is used on the set screws, use only the blue 242 or 243 type. The spline teeth should be coated with anti-seize or grease.

Referring to the following sequence, be sure the set screws engage the groove in the input shaft. A U-joint installed too far onto the shaft can prevent easy access to the bias adjustment screws.







5. Servo Direct Changeout

(reference: CF Rack exploded view and parts list)

The main reason for replacing the servo/pinion unit is to quickly substitute a different valve profile and/or torsion bar without going to the time and trouble of major disassembly.

This is the same procedure as shown on page 6, except that in this case only the servo flange is unbolted from the rack housing and the retainer cap is left undisturbed. The retainer cap contains a stack of 3 ball bearings which will guide the pinion nose into the previously adjusted position, and it will not be necessary to reset the backlash.

Note that a replacement servo absolutely must have the same number of teeth on its pinion as the one being replaced, i.e., a servo with a 12-tooth gear cannot be substituted for one with an 11-tooth gear, nor vice versa.

(1a) Disconnect the hoses at the servo (2). *Leave the rear bearing flange (30) in place.*

(1b) Using a single M600 hook spanner, break loose the snubber lock nut (9). Using anything that will conveniently fit the slot, unscrew the snubber screw (8) far enough to take the snubber (6) well out of contact with the rackshaft.

(1c) Using a T27 Torx Plus® wrench, remove the screws (27) and pull the servo/pinion assembly (2) out of the housing (1). The bushings (28 and 29) may come out with the screws; if not, remove them from the servo flange and set them aside for reuse. Do not lose the conical Belleville lock washers.

(1d) Insert the replacement servo/pinion assembly (2), being careful to guide the pinion teeth through the rack teeth and the pinion stem into the stack of 3 ball bearings (32) in the retainer cap (30). This will preserve the original backlash adjustment.

It will be helpful to orient the bias adjustment screws generally upward with the travel centered, to make them accessible in the car.

(1f) Install the concentric bushing (29) and its screw (27) with a Belleville washer. Lightly snug the screw. Put the other screw (27) and its lock washer into the eccentric bushing (28) and rotate the bushing until the single position is found where the screw will start. Install that screw. Tighten both screws, reset the snubber and reconnect the hoses.

If the retainer cap (30 or 37) has been disturbed or removed, the backlash will have to be reset following the procedure outlined in 5a.3 on page 6.

6. Ratios, Valves and Torsion Bars

Steering ratio: The overall steering ratio of a car is expressed as the turned angle of the steering wheel divided by the turned angle of the front tire—for example, 180° at the steering wheel producing 10° movement at the tire is 180÷10, or 18:1.

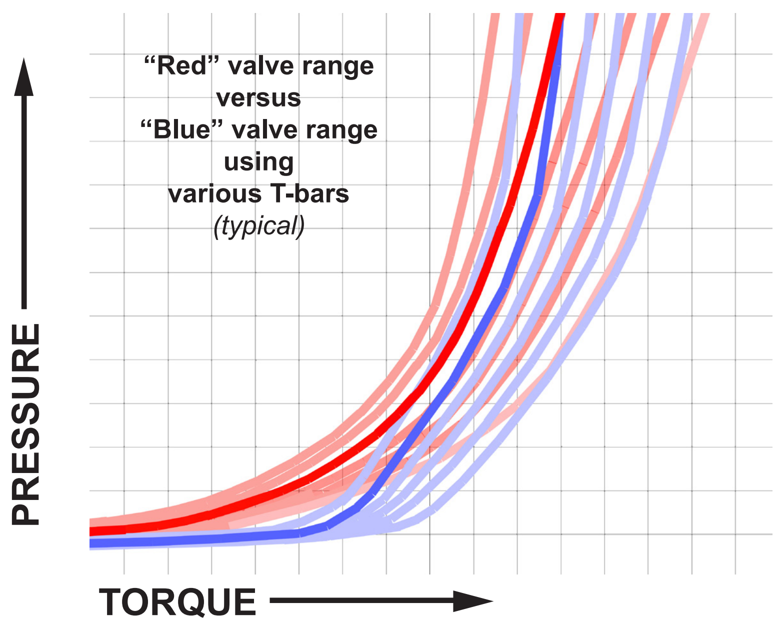
GEARBOX ratio: The ratio of a steering gearbox is the rotation in degrees of the input shaft divided by the rotation in degres of the output shaft. If the pitman arm is the same length as the steering arms, the overall ratio will numerically equal the gearbox ratio.

RACK ratio: A rack and pinion has only one rotating gear (the pinion) whereas its driven gear (the rack) moves only in a straight line. Convention defines its "ratio" as *the distance the rack moves in one turn of the pinion,* e.g. 2.62 inches/360°, 2.88 inches/360°—usually abbreviated as 2.62, 2.88, and so on. There are seven ratios in the Woodward CF series; from quickest to slowest these are 3.14, 2.88, 2.62, 2.36, 2.09, 1.83 and 1.57. The rack housing is machined for one specific ratio—easily measured, as well as traceable through the serial number.

While optimizing the rack ratio for a given driver and race track is somewhat outside the scope of this discussion, it can definitely be said that there is no "one size fits all" with respect to driver preference. As a general rule, the shorter the track the quicker the steering, *and the steeper the required response curve*—otherwise, the driver risks fatigue and can end up chasing the front end instead of controlling it.

Valve profile: Like the steering ratio, the preferred "feel" of the steering tends to be highly individualized. For that reason, four valve profiles are available, to produce four basic response curves. These are further modulated by nineteen interchangeable torsion bars, for a total of 76 standard permutations. The bar rate is *linear,* while the orifice cross sections are *progressive,* allowing the steering feel to be closely optimized by simply interchanging parts.

How the torsion bar modifies the response of the valve: For purposes of illustration, two different valve profiles are superimposed below. The "red" valve has a gradual, quasi-parabolic curve, while the curve of the "blue" valve shows two distinct changes in response rate (known as effort thresholds or "knees"). The lighter shades of red and blue show how a smaller-diameter torsion bar **steepens** the response curve of a given valve profile, whereas a larger-diameter bar **flattens** it.



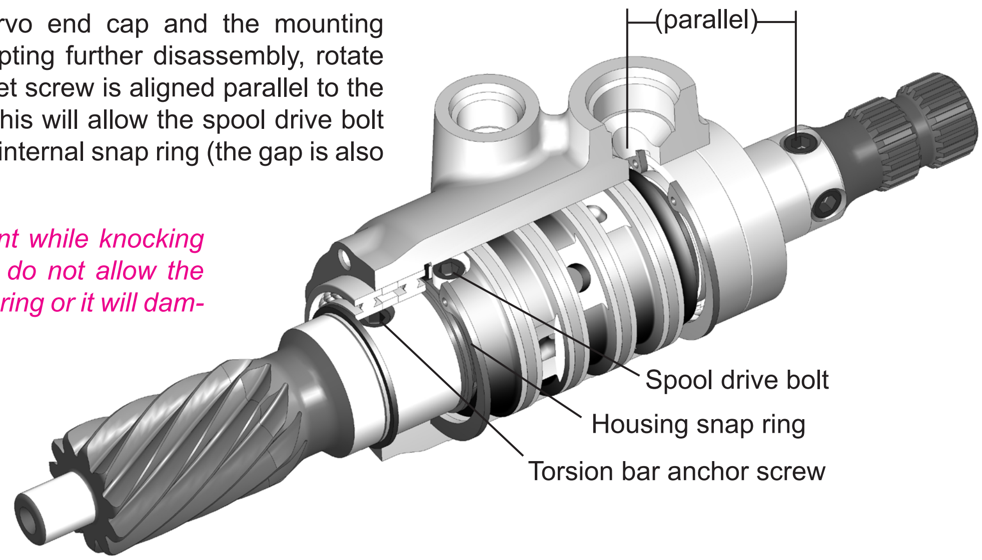
It will be seen that the "red" and "blue" response curves intersect. The crossover points and the areas of overlap show how different combinations can be employed to raise or lower the available assist with respect to the steered angle and the momentary position of the driver's hands. Like a preference for quicker or slower steering, some drivers are more comfortable with a definite effort threshold, and some prefer a response which more closely mirrors, or conforms to, the car's steering resistance.

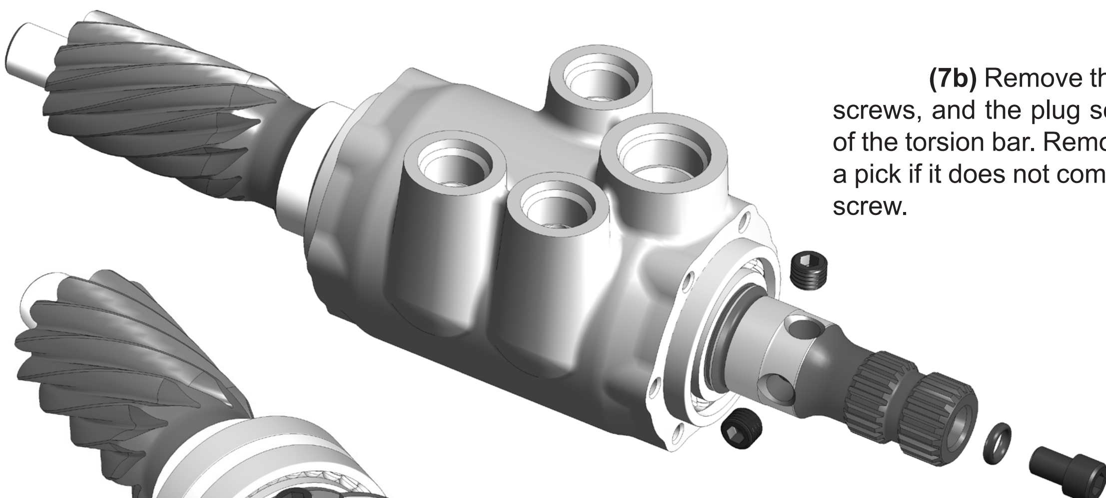
7. Changing out the torsion bar (reference: CF Servo exploded view and parts list)

The main difference between the CF type and other Woodward servos is that the torsion bar anchor screw is covered by the pinion bearings. To access the set screw the pinion assembly must be removed from the servo and its bearings pressed off. Removing the pinion is not at all difficult if these steps are followed and the cautions observed.

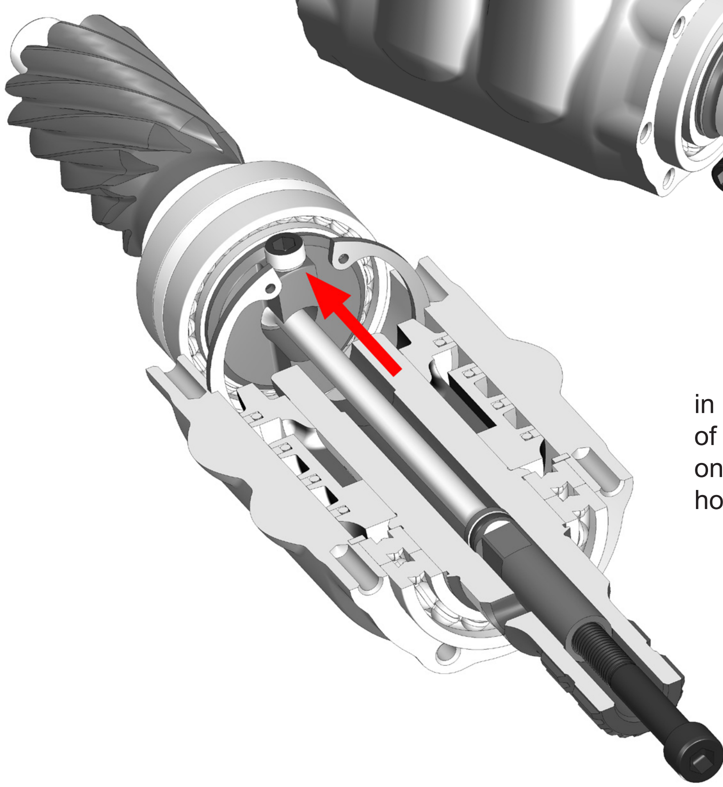
(7a) Remove the servo end cap and the mounting flange. Caution: before attempting further disassembly, rotate the input shaft until the right set screw is aligned parallel to the nearest fluid port as shown. This will allow the spool drive bolt to pass through the gap in the internal snap ring (the gap is also aligned with the hose ports).

Maintain this alignment while knocking out the pinion assembly, and do not allow the drive bolt to catch on the snap ring or it will damage the housing.





(7b) Remove the right and left set screws, and the plug screw from the end of the torsion bar. Remove the O-ring with a pick if it does not come out with the plug screw.



(7c) The pinion bearings are a light press fit in the housing. Install a 1/4-28 x 2 bolt in the end of the torsion bar. Using a light plastic hammer, tap on the bolt and drive the pinion assembly out of the housing.

Note: If the ring gap is oriented toward the hose ports as shown at left, the drive bolt will pass through the gap (NOTE: this alignment must be repeated at reassembly). While driving out the pinion and bearings, the extent of the gap can be felt by lightly turning the pinion back and forth so the drive bolt just contacts the lugs of the snap ring.

(7d) With the assembly free of the housing, remove the retaining ring from the pinion as well as the 1/4-28 x 2 bolt. Place the assembly in the receiver (tool V542) and press the pinion out of the ball bearings. This will expose the anchor set screw. Back off the screw to allow removal of the torsion bar. The T-bar can be pulled out of the pinion by hand.

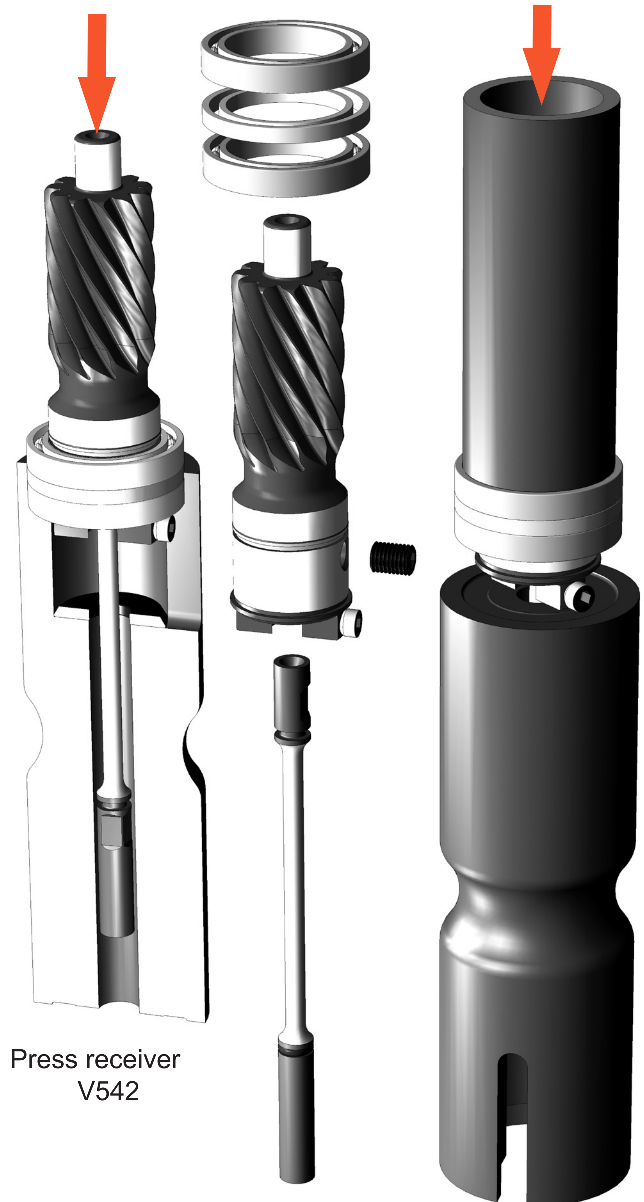
Caution: The set screw has a very slightly concave machined surface and it seats very tightly on the anchor flat of the torsion bar. To prevent injury when it breaks loose, wrap a shop rag around the handle of the hex wrench, or wear a glove.

Note that the ball bearing stack varies with the diameter of the pinion. Referring to the CF Servo exploded view, larger pinions use the large-bore ball bearings with spacers (16) with the large spiral retaining ring (17). Smaller pinions use the same bearings (9) and snap ring (10) as the valve input shaft (3).

(7e) Insert the new torsion bar and tighten the anchor set screw. The set screw should be seated on the T-bar flat tightly enough that it will break loose with a snap as described above.

Blue Loctite® 243 can be used on the threads, but do NOT use Red Loctite® 271, or any other threadlocking compound intended for permanent assembly.

To reassemble the servo, perform all the foregoing steps in reverse order. Tool 542 is reversible to support the tang end of the pinion, and it includes pusher tubes for pressing the bearings back on. After reinstalling the servo in the steering rack (or, alternatively, in a dedicated servo test rig) use the bias adjusting screws to balance the pressure.



Press receiver V542

Pinion disassembled and T-bar removed

Press receiver inverted for reassembly

Further teardown for seal and/or bushing replacement:

Step (7e) above represents the limit of the "race preparation" phase of service and maintenance. Note that at this point the servo will have been disassembled far enough to allow a valve changeout, or replacement of the high-pressure spool seals. Also, once the servo has been separated from the rack housing, the rack itself can be disassembled and the high-pressure cylinder seals and/or the rack bushings replaced, and/or mechanical repair of crash damage performed.

Before arbitrarily replacing high-pressure seals and/or rack bushings, always perform a leakage test and/or a mechanical evaluation to determine whether the unit actually needs rebuilding.

Testing

Bench Testing the type CF Power Steering Rack

Mechanical evaluation: A hydraulically assisted steering rack is an extremely simple device. Its mechanical output operates in a straight line, and that function can be easily tested by simply turning it lock to lock in the car with the wheels off the ground and the engine off. Damage resulting from an on-track incident, such as a bent rackshaft, will be immediately apparent. Detection of a slight mechanical irregularity in the steering, such as a tight spot from damaged rack teeth, is made easier by actually pushing and pulling the tires themselves lock to lock, as opposed to turning the steering wheel. On the bench, turning the pinion with the spline tool will likewise show up any mechanical problems.

Hydraulic evaluation: Apart from obvious crash-related damage, the principal defect that will degrade the rack's performance is **internal leakage anywhere in the working side of the hydraulic circuit.** As with any hydraulic cylinder, leakage can be analyzed by simply pressurizing it against the travel stops and measuring the pressure in the working side and the flow out the exhausting (return) side. **Note that it is not necessary to mount the rack to a surface; simply testing the rack against its own hard stops in both directions will reveal any internal sealing defect.**

Equipment: An easily-constructed test rig consists of a motorized pump and reservoir, a pressure gauge with a range that will handle the pump being used (preferably with at least a 2% full-scale accuracy and filled with glycerin to resist shock) and a flowmeter with a range of 0-2 GPM (0-7.5L/min). Connect the gauge into the pressure line from the pump to the servo, and the flowmeter into the return line from the servo to the reservoir. With the pump running, the flowmeter will show the flow through the circuit. Although with a variable-speed drive the rig can be used to map the output of a pump and plot its output curve as shown on page 5, that extra complexity isn't needed for leak-testing a rack. The main thing is to *detect* and *measure* any flow in the return with the pump in relief.

Procedure: Using the spline wrench or other convenient tool (such as Vise-Grip pliers) on the input shaft, turn it to full lock one way and increase your input torque until the pump goes into relief. At that point the flow through the return should stop immediately. If it continues, there is leakage somewhere on the working side of the system. Although it is extremely rare for leakage to occur in only one direction, you should always test both left and right.

In the above picture, the rack is held against its stop at full left lock, which has put the pump into relief, in this case at about 1500 PSI. The flow rate is zero, which confirms that all seals function perfectly when steering to the left.

Holding the rack at full right lock has put the pump into relief within about 1% of left lock, which is well within normal variation. The flow is again zero, confirming that all seals function perfectly when steering to the right.

Note that flow during relief of 0.2 GPM or less does not indicate an immediate need to replace seals, as that leakage rate is generally too low to affect the steering. As a general rule, the quicker the steering ratio, the more leakage can be tolerated before it is actually felt as weakened steering response. However, before reaching that threshold, the leakage will have begun to generate waste heat. In any case where high underhood temperatures are a condition of normal use, it is a good idea to run this quick test after every race.

Leakage Analysis

High-pressure seal leakage: Seals in the rack that are relevant to working pressure are the *rod seals* (16) at each end of the cylinder (shown below) and the *piston O-ring* (19). The relevant seals in the servo are the *spool seals*. Flow detected during relief indicates leakage past one or more of these. Leakage from the right rod seal should be directly observable (with the rack boot removed and the rackshaft wiped clean) as clear power steering fluid. Leakage from the left rod seal is less obvious, as it empties into the gear case. Oil plus the heat of operation will tend to liquify the rack grease and the oil/grease mixture will appear on the rackshaft (again, with the rack boot removed and the shaft wiped clean).

Failure due to chemical attack by incompatible fluid:

This photo shows two identical rod seals from two different racks, both in service for about 60 days circa 2002. The material at that time was urethane, which, although more chemically vulnerable than the DuPont Viton® currently used in these seals, serves to illustrate the effects of aggressive fluids.

The internal energizing O-ring (orange arrow) *is actually present in both seals,* but the one at right has shrunk by about 20% along with the rest of the seal, having been run with a certain aftermarket "synthetic" fluid (which will remain unnamed) until its elasticity was reduced to approximately that of bacon.

While in this case the rackshaft acted as a mandrel and prevented the inner diameter from getting any smaller, the outer diameter shrank enough that it pulled completely out of contact with its groove and allowed fluid to leak around the seal from gravity alone whenever the engine was shut off and the steering depressurized. With the engine running, static pressure kept the dead seal “inflated” in its groove and reduced the leakage from the cylinder enough that the car still steered without complaint from the driver. However, such a condition should not be counted on to continue indefinitely.

The rod seals currently used in Woodward racks are made from DuPont Viton® and tested for 168 hours in Dexron® III at 300°F. Although they will withstand excursions to 400°F., lengthy exposure above 300° requires a leak test at the very least (and, *possibly,* replacement) prior to the next race. Do NOT use Dexron® IV. With Dexron® IV the rod seals may come to resemble the picture.

Note: leakage across the PTFE/glass rings in the servo spool typically occurs only after wearing away the hard anodized layer inside the bore, a process that can take years unless accelerated by debris from a deteriorating pump.

Low-pressure seal leakage: The chambers containing the servo input shaft and pinion seals are connected to the exhaust (return) side, which means that ***leakage from those seals has no effect on working pressure and cannot by itself cause loss of steering.*** Low-pressure seal leakage is generally not detectable by reading the flowmeter, but is usually pretty obvious by itself. The inner seal on the pinion will leak into the gear case, as described in **2a,** while the outer seal on the input shaft will leak directly onto the floor.

Typically, leakage will be first noticed after the car has been parked for some time with the engine off and a puddle has formed. To test the severity of the leak, dry the area around the suspected leak and start the engine. With the engine running, the no-load pressure in the system will often be enough to expand the seals as described above, and they may be fully functional for an extended period—however, they will immediately begin leaking again when the engine is turned off.

Seal Replacement

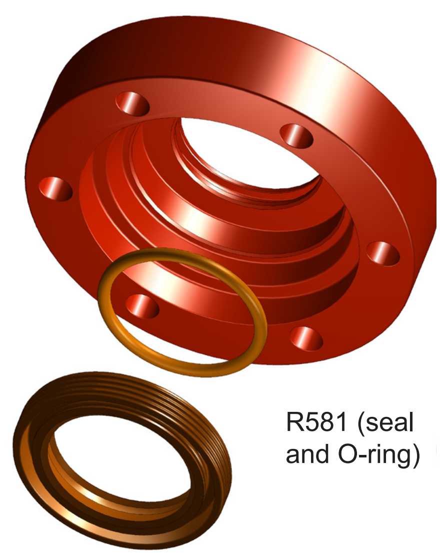
1. Low-pressure seals (reference: CF Servo exploded view and parts list)

Detach the servo/pinion unit from the steering rack by removing the two screws (18). Mark the mounting flange (22) and the housing (1b) so the ports will be aligned correctly for reassembly. It is not necessary to mark the end cap.

(1a) Input shaft seal: Remove the six screws (12) from the end cap and separate it from the housing. The cap is not a press fit on the bearing, but blue Hylomar® sealant is present. It is not necessary to pry the flange away from the housing, nor off the input shaft.

The R581 seal set consists of a spring-loaded lip seal and an outer protective O-ring. The function of the O-ring is to keep debris and pressure-washer fluid away from the lip seal. Remove the O-ring with a pick and replace it by hand.

To replace the lip seal, gently insert a small bent 1/8” flat screwdriver or similar tool under the lip of the lip seal and push the seal out of the flange. Be sure all sharp edges are polished off your tool to prevent damage to the machined surfaces. The seal is metal-backed but its contact surface is Viton® rubber and it will come out easily. Wipe a film of petrolatum on the new seal and push it into the bore—taking care not to turn the lip under, which will allow the spring to escape.

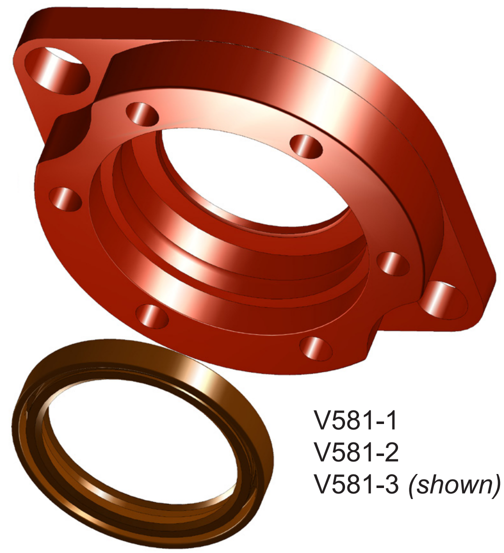


R581 (seal and O-ring)

(1b) Pinion seal: Remove the six screws (12) from the servo mounting flange and separate the flange from the housing. The flange is not a press fit on the bearing but blue Hylomar® sealant is present at the flange/housing interface. It is not necessary to pry the flange away from the housing, nor off the pinion.

The flange and seal are made in three sizes corresponding to the diameter of the pinion journal (refer to the CF Servo exploded view and parts list).

To replace the lip seal, gently insert a small bent 1/8” flat screwdriver or similar tool under the lip of the lip seal and push the seal out of the flange. Be sure all sharp edges are polished off your tool to prevent damage to the machined surfaces. The seal is metal-backed but its contact surface is Viton® rubber and it will come out easily. Wipe a film of petrolatum on the new seal and push it into the bore—taking care not to turn the lip under, which will allow the spring to escape.



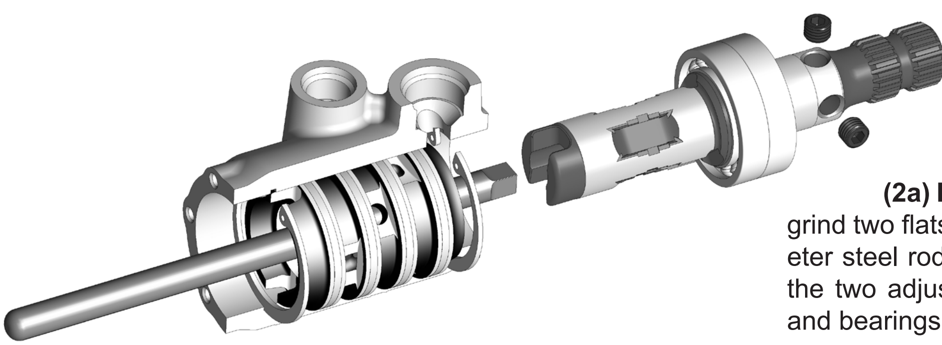
V581-1
V581-2
V581-3 *(shown)*

(1c) Reassembly*: Before reinstalling the end cap and mounting flange, clean any sealant from the holes and the mating surfaces. Inspect the #10-24 tapped holes in the housing and blow out any dried sealant residue. Apply a new film of Hylomar® or equivalent sealant, being careful not to get any in the tapped holes. *Caution: If a cap screw bottoms out on sealant it will crack the housing.* Apply petrolatum to the input shaft and pinion and carefully ease the seals onto their journals, taking care not to turn the lip under. Reinstall the screws and snug them in an alternating “star” pattern to 30 inch-pounds, with final tightening to 50 inch-pounds.

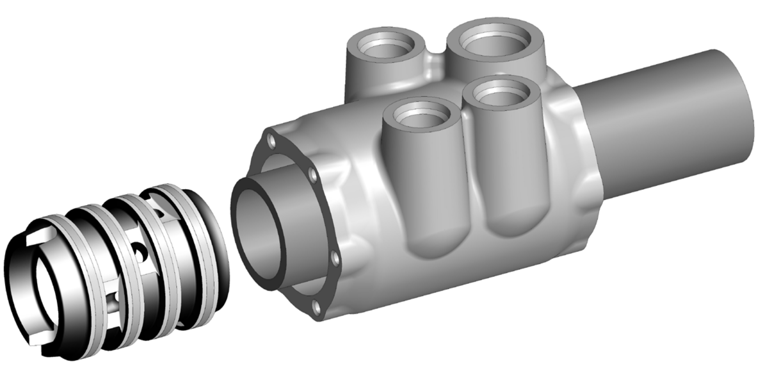
**To proceed with high-pressure seal replacement, postpone reinstallation of the ends cap and flange.*

2. High-pressure seals (spool rings) *NOTE: This procedure continues disassembly after Race Preparation Step 7, “Changing out the torsion bar”)*

Description: The valve assembly consists of an input shaft and a spool. These parts rotate with respect to each other but are so closely fitted that fluid will not flow through the clearance gap even under high pressure. As a general rule, the shaft and spool should be kept as a matched assembly and not substituted individually.



(2a) Removing the input shaft: Mill or grind two flats at 90° on the end of a 3/8” diameter steel rod. Secure it in the input shaft with the two adjusting screws, and drive the shaft and bearings out with a plastic hammer.



(2b) Removing the spool: Extract the internal snap rings (5) from the housing, taking care not to raise any burrs that will cut or otherwise damage the spool seals. Use a convenient piece of 1” schedule 40 PVC pipe to push the spool out of the housing in the direction shown. A spool assembly that has been in a housing for any length of time will slide out easily, as its semi-rigid PTFE rings will have conformed to the bore.

(2c) Replacing the spool rings: Remove the old rings with a suitable pick, taking care not to scratch the grooves or lands. While the four energizing O-rings can be stretched over the lands by hand, the PTFE rings are glass-reinforced and of limited elasticity *(note: old rings cannot be removed and reused).* Slide the rings over the V598 mandrel one at a time, and install them into the middle grooves first. While pushing, support the ring as evenly as possible to keep it round. Lubrication is not necessary at this point.

(2c.1) Immediately squeeze the installed ring by hand to help it return to its original diameter and roundness. When all four rings are in place, push the spool into the installation sleeve V599. Push from the end with the two drive bolt slots and be sure the rings are being evenly compressed by the taper.

(2c.2) Expose the first land from the sleeve by about 75% of its width. The land will act as a pilot for insertion of the spool into the housing.

Leave the assembly in the installation sleeve for at least 30 minutes to allow the rings to conform. Always use this procedure, whether you are doing a complete seal replacement or simply installing a new preassembled valve.

Failure to allow the rings enough time in the sleeve may cause them to catch on the snap ring groove. If PTFE shavings are seen after installation, the rings have been damaged and will probably leak.

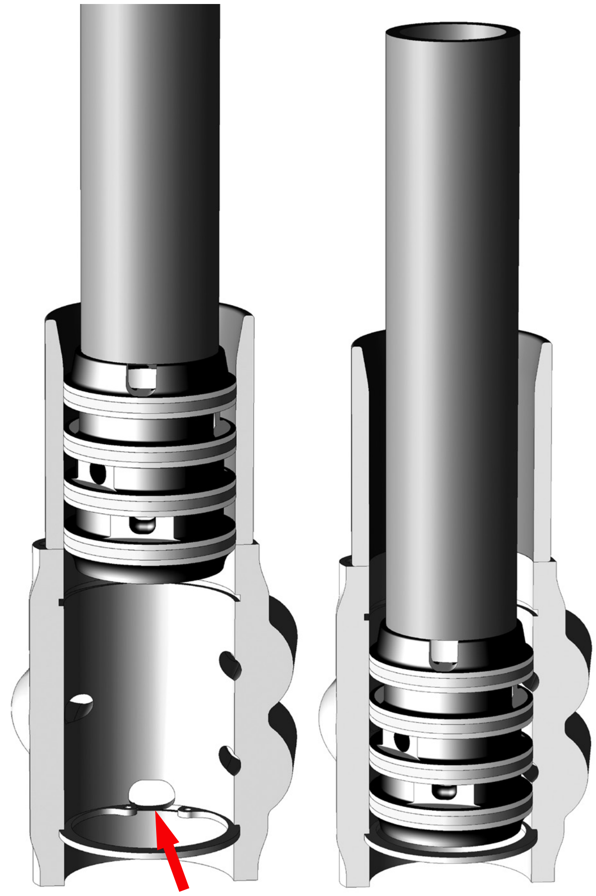
(2c.3) Position the servo housing with its return port toward the bench and a snap ring installed in the lower groove. Orient its gap toward the ports as shown by the orange arrow. This will provide clearance for reinsertion of the pinion with its protruding spool drive bolt. Note that in this position its gap also straddles the relief port opening.

Coat the inside of the housing with assembly petrolatum, *completely filling* the empty upper ring groove. This will allow the spool rings to skate past it without catching.

(2c.4) Start the exposed spool land into the housing. Using the same 1” PVC pipe, rapidly push the spool through the installation sleeve and into the housing until it stops against the lower snap ring. Although this requires fairly low effort, an arbor press (or, in a pinch, a drill press) will perform the operation more smoothly.

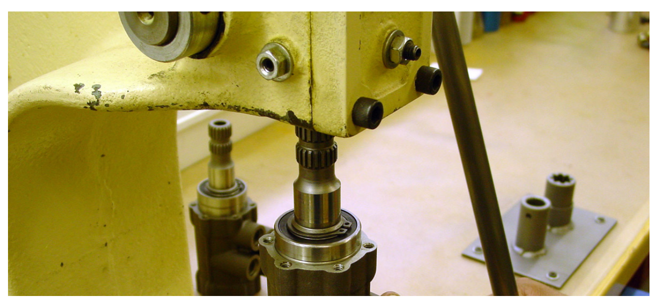
(2c.5) Reinstall the second snap ring in the upper groove, orienting its gap toward the ports and aligned with the gap in the first snap ring.

Rotate the spool so that one of its two drive bolt slots is centered on the gap (red arrow at right and bottom).

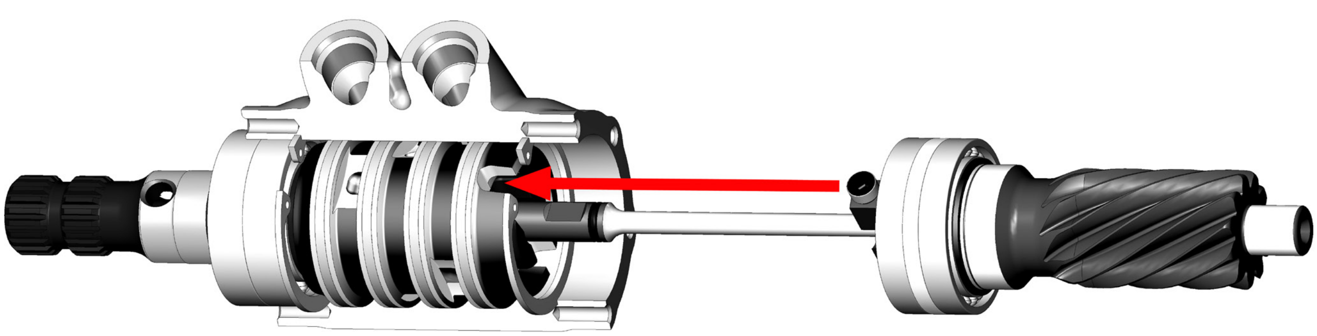


(2d) Valve input shaft reinstallation: Invert the housing for installation of the valve input shaft. Note that the input shaft enters the spool from the end without the drive bolt slots. Coat the valve input shaft with petrolatum and start it into the spool.

Using an arbor press, push the shaft assembly into the housing until the bearings stop against the snap ring. *(Caution: Do not drive the assembly in with a hammer).*



(2e) Pinion reinstallation: Rotate the input shaft so that its drive slot is aligned with the drive bolt slot in the spool. Coat the torsion bar O-ring with petrolatum and insert the pinion assembly, keeping the drive bolt aligned with the ring gap and the slot in the spool. Once the bearings contact the housing the drive bolt will no longer be visible, so care must be taken to press the assembly straight in. While doing this you can turn the pinion back and forth as in step (7c) to be sure it clears the snap ring. For reference, when fully installed against their snap rings the bearing stacks will protrude from the housing about .209” at each end.



(2f) Servo reassembly: As in step (1c) above, before reinstalling the end cap and mounting flange, clean any sealant from the holes and the mating surfaces. Inspect the #10-24 tapped holes in the housing and blow out any dried sealant residue. Apply a new film of Hylomar® or equivalent sealant, being careful not to get any in the tapped holes. *Caution: If the cap screws bottom out on sealant it could crack the housing.* Apply petrolatum to the input shaft and pinion and carefully ease the seals onto their journals, taking care not to turn the lip under. Reinstall the screws and snug them in an alternating "star" pattern to 30 inch-pounds, with final tightening to 50 inch-pounds.

The final step in servo reassembly is to reinstall the bias adjustment screws, the plug screw and O-ring, and any hose adapters that were removed.

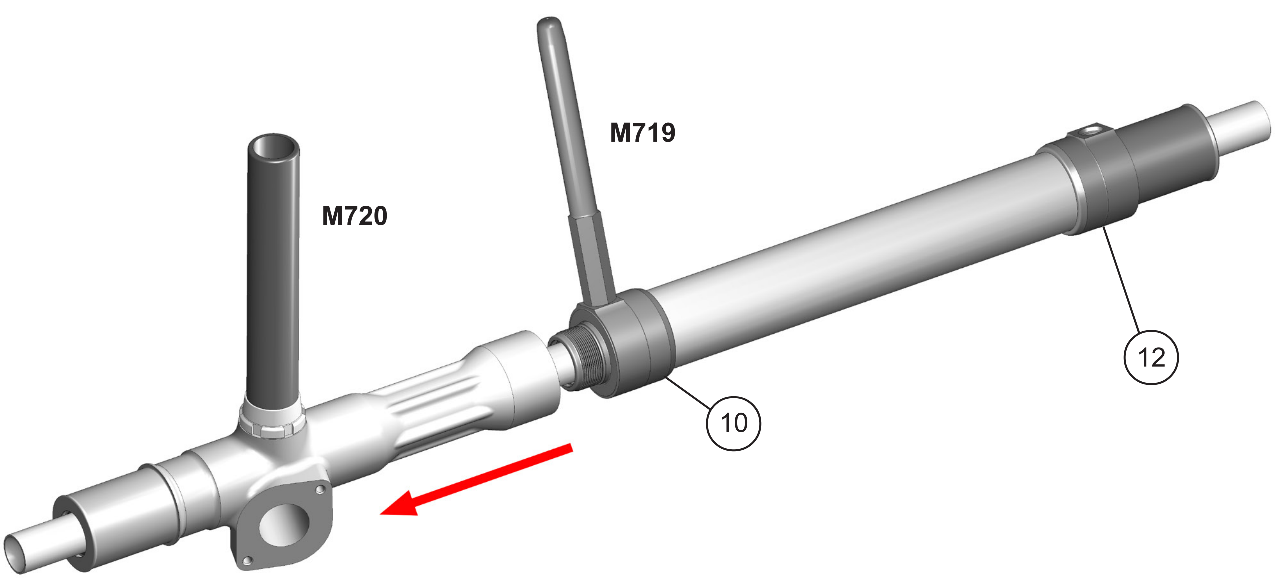
(2g) Testing: With hose adapters in place the unit can be connected to a leak-testing device *without being installed in a rack.* All that is necessary to leak-test a servo by itself is to restrain its output end (the pinon) while turning its input shaft and reading the pressure gauge and flowmeter as described under "Testing" on page 16.

3. High-pressure seals (rack cylinder) (reference: CF Rack exploded view and parts list)

High-pressure sealing in the cylinder is accomplished by two special-profile Viton® U-cup shaft seals (which have superseded the Polypak® style loaded lip seals used before 2019) and a Viton® (or generic fluorocarbon) piston O-ring. There are two common industrial options for the piston O-ring, the standard 75 durometer, and a 90 durometer tested with the Big Bore option. The harder compound resists extrusion and "nibbling" at extreme pressure, but slightly increases breakaway torque. Any wear advantage of the hardfer compound has probably been rendered inconsequential since the big bore option effectively reduces steering pressure below the extremes that were encountered at some tracks during the 2022 season. Either compound is entirely functional and can be used according to preference.

(3a) Unscrew the rack housing from the cylinder: Remove the boots and the monoball ends from the rackshaft. Remove the snubber and the servo/pinion assembly. Remove the 90° hose adapters from the ends of the cylinder. Screw the housing wrench M720 into the snubber bore and tighten its jam nut with the M600 spanner (this is important—*never* use a threaded-hole wrench loose or it will damage the threaded hole). Screw the cylinder port wrench M719 into the -6 port of the cylinder adapter (10) and tighten it with an 11/16 wrench (as above, do not use this tool loose or it will damage the port). Unscrew the housing from the cylinder adapter.

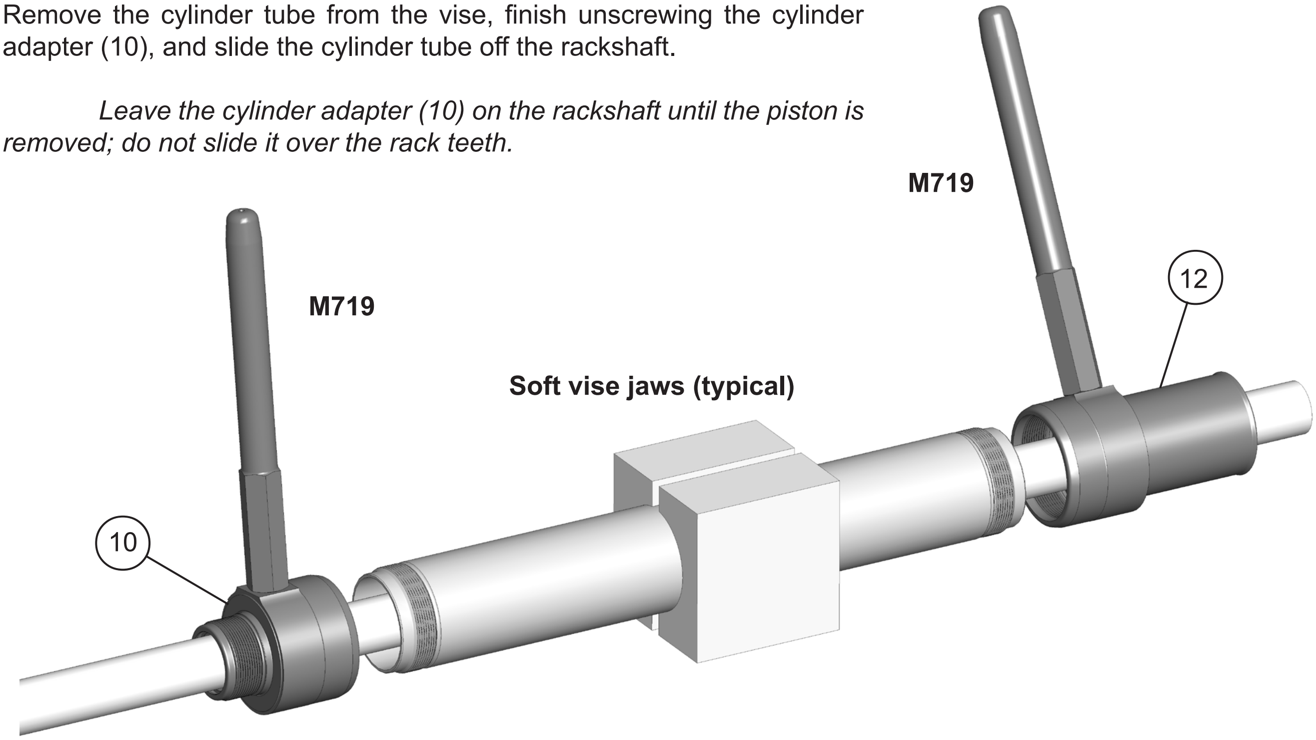
*Caution: The threaded joint is assembled with blue Loctite®243 and some force will be required to break it loose. For convenience, tool M720 can be held in the bench vise. All these wrenches have provision for use with cheater pipes, should that be necessary to overcome the threadlocking compound; however, cheater pipes should **never** be used in reassembly.*



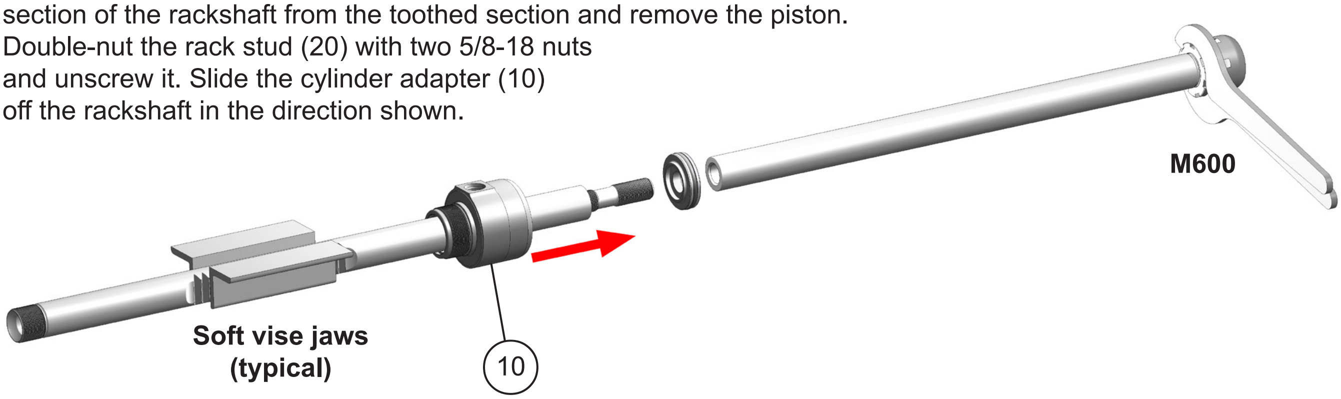
Slide the housing off the toothed end of the rackshaft and set it aside (repair and rebuilding of the housing involves replacing the rack bushings and is covered in another section).

(3b) Break the ends loose from the cylinder: Hold the cylinder tube with a pair of machined, closely fitting soft jaws in a vise as shown below. ***Do not grip the cylinder tube with plain vise jaws, locking pliers, or a pipe wrench.*** Install a second M719 tool into the fluid port of the outer cylinder end (12) and tighten it with an 11/16 wrench. Unscrew the outer cylinder end (12) and slide it off the rackshaft. Remove the cylinder tube from the vise, finish unscrewing the cylinder adapter (10), and slide the cylinder tube off the rackshaft.

Leave the cylinder adapter (10) on the rackshaft until the piston is removed; do not slide it over the rack teeth.



(3c) Holding the toothed section of the rackshaft in the vise with flat soft jaws, install a monoball lock nut (24) and a monoball adjuster (23), tightening both together with a pair of M600 hook spanners. Unscrew the plain section of the rackshaft from the toothed section and remove the piston. Double-nut the rack stud (20) with two 5/8-18 nuts and unscrew it. Slide the cylinder adapter (10) off the rackshaft in the direction shown.



At this point, all blue Loctite® 243 residue should be cleaned off the rack stud, the tapped holes in the rackshaft, the threads of the cylinder adapter, and the threads in the rack housing.

Caution: The end faces of the rackshaft, the counterbores of the piston, the face of the cylinder adapter and its mating face on the rack housing are critical register surfaces and care must be taken not to scratch or raise burrs.

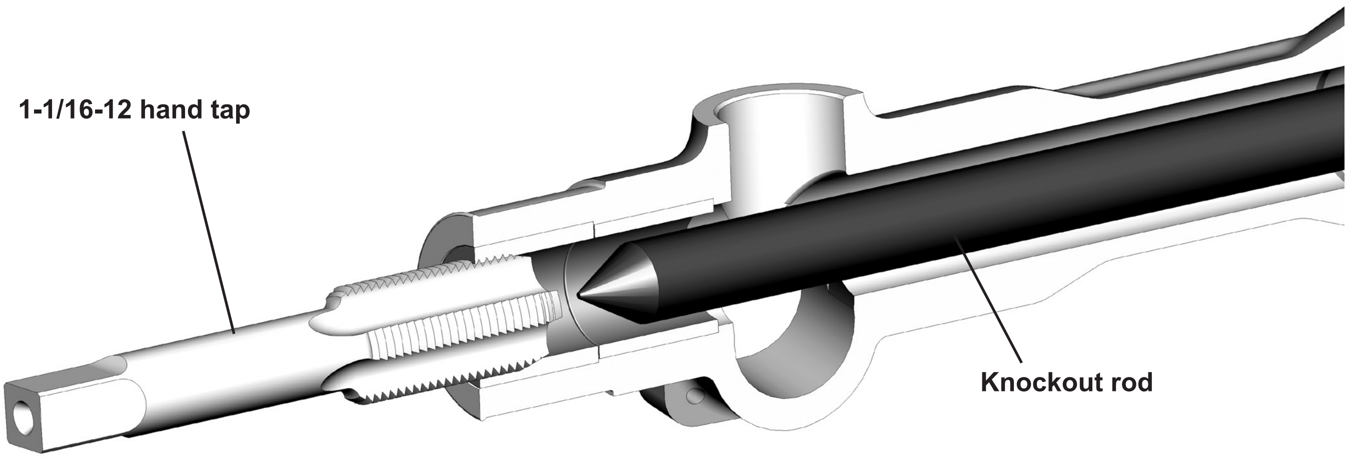
(4) Remove all old seals, wipers and O-rings with a pick. This step completes the disassembly procedure for purposes of resealing. If rack bushings are to be replaced, do that next, before installing new seals.

Rack Bushing Replacement
(reference: CF Rack exploded view and parts list)

The rackshaft is guided in bronze sleeve bearings at three points for minimum deflection. Depending on the model, the unit may have a total bearing length exceeding five times the shaft diameter.

1. Bushing removal

The bushings are pressed into their bores; if up against a full-height shoulder, their inner end faces are not accessible to a bushing driver. However, they are easily extracted with a 1-1/16-12 tap (the thread size used for an AN-12 O-ring boss). Turn the tap in about half an inch and drive the tap out with a pointed rod as shown below, engaging the point in the tap's center hole. The bushing will come out with the tap. Unscrew the tap and remove the next bushing the same way (*Note: a 3/4 NPT pipe tap will work if a 1-1/16-12 straight tap is not available).*



The illustration is representative; various models of CF racks will have different bushing combinations—for example, a single bushing rather than a tandem pair. In the Nextgen CF, both ends of the rack have an identical bushing stack: the inner is 1 inch long and the outer is 1-1/4 long. Install new bushings in the same order.

Extraction and replacement of the bushings from the cylinder adapter (10) and the outer cylinder end (12) is accomplished in the same way. Leave out all wipers and seals until the rackshaft has been fitted to the preassembled parts.

2. Bushing replacement

(2a) Installation: Using a piloted bushing driver and a light hammer (or a tall arbor press) install new bushings in all the bores, making sure to start them squarely. Drive the first bushing full depth until it seats solidly against the housing shoulder, and the second until it seats against the first bushing. At full depth the outer bushing end will be .010 below the end face of the housing.

Regardless of the method used to install the bushings, take extreme care to shield the housing from damage to its opposite end, as that is a critical alignment surface used to square the cylinder adapter (10) to the housing. The best way is to embed the housing in a pile of shop towels and drive the bushings freehand with a piloted driver and hammer.

The cylinder adapter (10) and outer cylinder end (12) are short and will fit conveniently under the ram of an arbor press.

(2b) Housing preassembly test: Prior to installing any wipers or seals, temporarily screw the cylinder adapter (10) into the housing. *Do not assemble these parts dry; use assembly petrolatum or similar lubricant on the threads to prevent galling.* Reversing the procedure shown on page 22, make up the joint firmly. Verify the rackshaft will slide freely in the assembly without binding. If it will not, the housing bushings will have to be touched up on a Sunnen hone. At this point, remove the cylinder adapter (10) and set it aside.

The housing bushings are more than two diameters long and will provide good support for the hone mandrel *(do not use a brake hone, as it cannot preserve alignment nor guarantee roundness, and will risk bellmouthing the bore).* Take reasonable care, as a good close running fit will pay dividends in service life.

Rack Reassembly

(reference: CF Rack exploded view and parts list)

1. Rackshaft, piston and cylinder

(1a) Install rod seals and wiper: After honing the bushings (as necessary), clean all lubricant and other residue from the threads and mating surfaces of the cylinder adapter (10) and the outer cylinder end (12). Install the wiper (14), the rod seal (16) and O-ring (15). Do the same with the outer cylinder end (12).

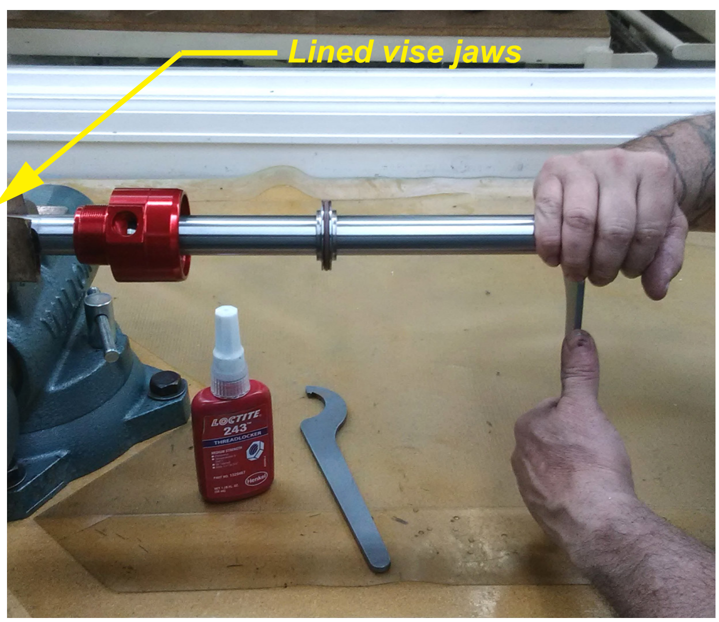
IMPORTANT: Steps (1b) and (1c) are time-critical and must be completed within the ten-minute setting time of Loctite® 243.

(1b) Rackshaft and piston: Hold the rack teeth in a bench vise, protected with soft metal or fiber shim material. Slide the assembled cylinder adapter (10) onto the toothed section of the rackshaft, being careful not to catch the lip of the wiper and turn it under. ***Note: Regardless of the particular style of rod seal and wiper, the lip of the wiper always faces toward the rack teeth and the lip of the rod seal faces toward the piston.***

Reversing the steps on page 23, double-nut the rackshaft. Apply Loctite® 243 to the rack stud (20) and screw it by hand into the toothed half of the rackshaft until the relieved section of the stud is flush with the end of the shaft. Don't bottom out the stud; leave it slightly loose.

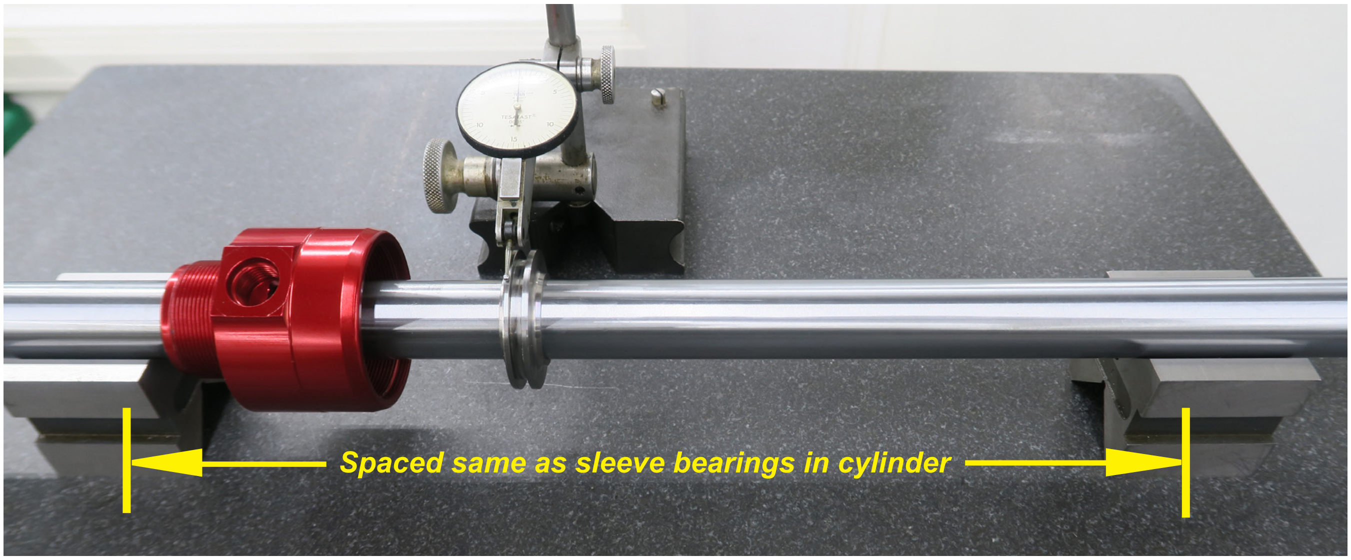
Note: The stud is a floating tension fastener and it has no alignment function. Concentricity and parallelism of the two halves of the rackshaft are provided by the piston counterbores.

Install the piston (18), wiping off excess Loctite®. Run the other half of the rackshaft onto the stud and tighten with the M600 wrench on the monoball adjuster (23). Leaving the monoball nuts in place, *remove the assembled rackshaft from the vise and proceed immediately to test.*



(1c) Testing alignment: As pictured on the next page, support the assembled rackshaft in two vee blocks on a surface plate. Space the blocks approximately as far apart as the bushings in the ends of the cylinder to accurately simulate the completed assembly.

Test the runout either on the periphery of the piston or on the shaft immediately adjacent to it. The maximum permissible runout is .0025 TIR. If this reading is exceeded, immediately break the connection loose, snug it up just enough to provide drag against the piston, rotate the piston a quarter turn, retighten the connection and retest.



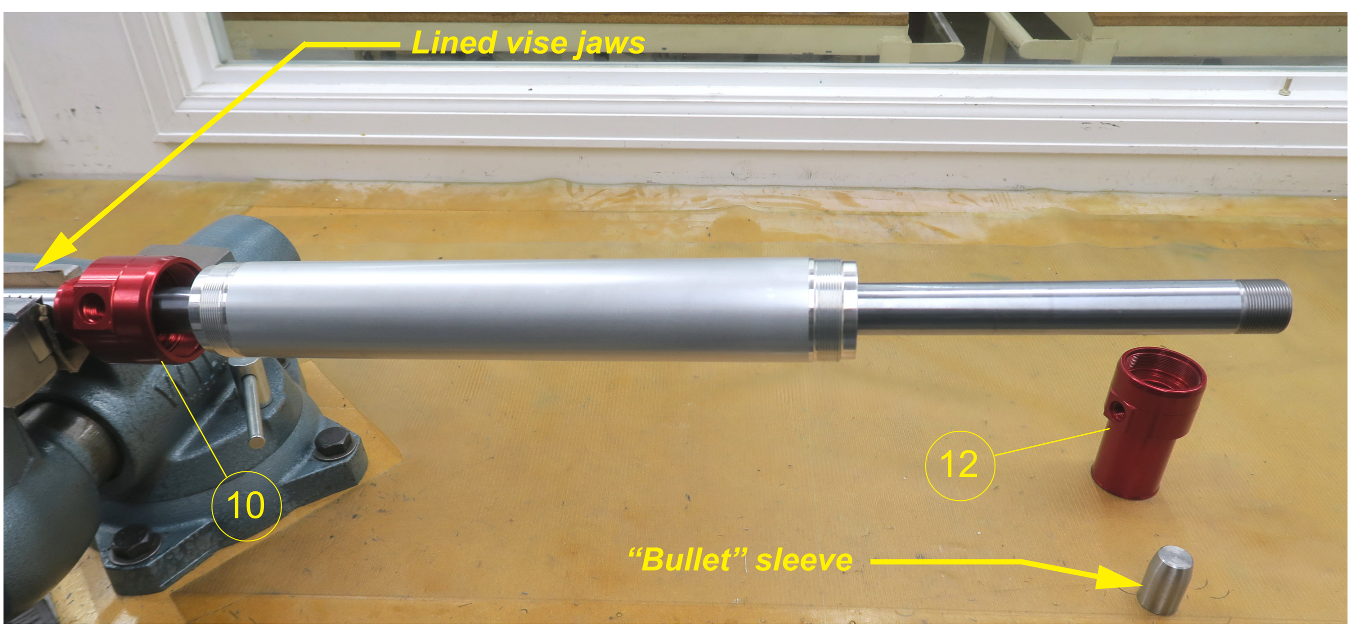
Rackshaft alignment test setup (typical)

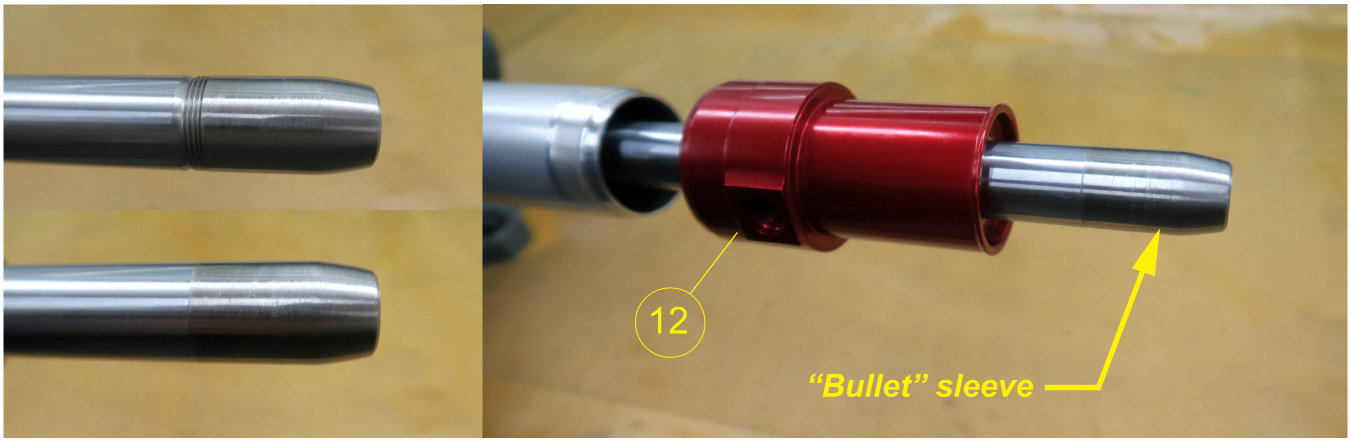
Repeat this procedure until the shaft runs true within .0025 TIR. If you cannot obtain statisfactory alignment within the ten-minute setting time, take it back apart, clean off the Loctite® and reface the shaft ends dead square. Any deviation from squareness should be toward concavity. If debris has damaged the inner faces of the piston counterbores, refinish those as well, but do not touch the bores. Make sure to chamfer the shaft ends (45° x .020) to clear the inside corners of the piston. The shaft is hard chromed and care must be taken to remove any burr from the chamfer. *Turn the chamfers; do not use a file.*

Note that the function of the Loctite® is to lock the **threads** after alignment has been established; it is not necessary to glue the piston. When you are satisfied that the rackshaft assembly is straight and true, remove the monoball nuts and wipe off any Loctite® residue. Without installing any seals, assemble the cylinder tube and its ends as described below, to test the sliding fit of the bushings. If it is bind-free, disassemble and install the seals, O-ring and wiper, and proceed with step (1d).

(1d) Cylinder reassembly: Holding the assembled rackshaft in the vise (making sure to protect the teeth with soft jaws or fiber shim material) install the piston O-ring (19) in the groove of the piston (18). Coat the piston and the inside of the cylinder tube (17) liberally with assembly petrolatum or Vaseline, and slip the tube over the piston.

Before screwing the tube into the cylinder adapter, **apply anti-seize compound to the threads.** The parts can be screwed together by hand (the fit will tighten somewhat as the end of the cylinder enters the O-ring).

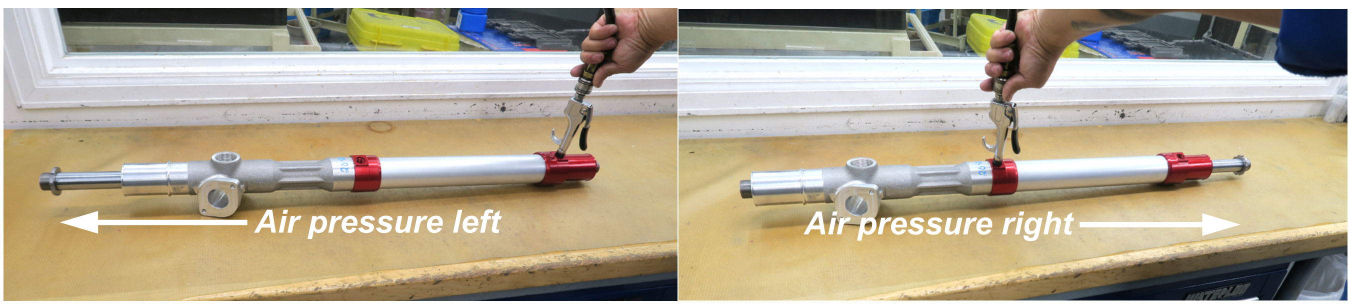




Install the bullet sleeve over the threads on the end of the rackshaft and coat it with assembly petrolatum or Vaseline. The sleeve will allow the rod seal to slip over the threaded section without tearing. A dimensioned drawing of the sleeve is provided in the Appendix. ***Note: the inner lip of the seal will absolutely not pass over the bare threads without the sleeve.*** Apply anti-seize to the threads and screw the outer cylinder end (12) onto the cylinder tube. Make up the connection with two M719 screw-in wrenches, reversing the procedure shown on page 23.

It should be possible at this point to move the cylinder by hand, allowing for minor “stiction” from the piston O-ring and the new rod seals.

To prevent accidental travel into the rack teeth, which will catch and ruin the rod seal in the cylinder adapter (10), temporarily install the completed cylinder assembly into the rack housing and ***install the monoball lock nuts (24) on both ends of the rackshaft to act as travel stops, as shown below:***



(1e) Testing your assembly: With the unit on the bench, apply shop air with a rubber-tipped blowgun. The rackshaft should easily and positively pop from full left to full right. Hold at the end of travel and listen. The hissing of air escaping past a leaking seal will be obvious. This test will save a great deal of time and trouble compared to waiting until you can hook up the complete rack to a fluid supply. Note that elastomeric seals tend to seal tighter with additional pressure, so if your assembly job works with air, it will surely work with oil.

With the leak test complete, unscrew the cylinder adapter (10) from the rack housing per the illustration on page 22, and reinstall using Loctite®243 on the threads.

At this point, major rebuilding of the CF rack is complete, and it remains only to reinstall all previously removed components in reverse order, beginning with the servo/pinion assembly.

Remember that the servo pinion must be compatible with the rackshaft and housing, e.g., a 1.57 pinion cannot replace a 2.09, nor the other way around.

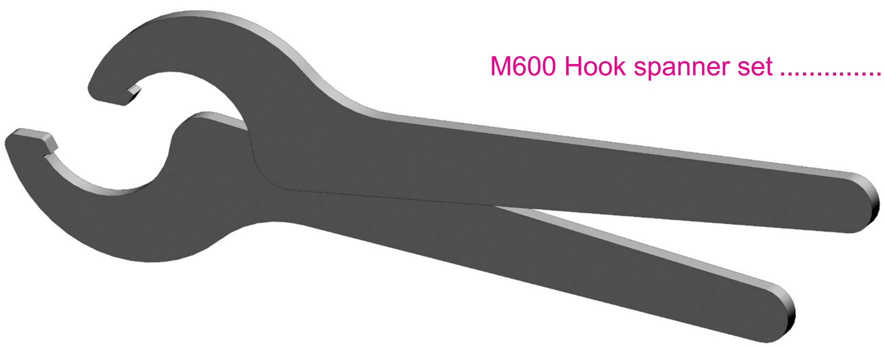
Although the servo and cylinder will have been tested separately, it’s always a good idea to test the assembled steering rack to verify that the hose connections are tight.

Appendix I: Service tools

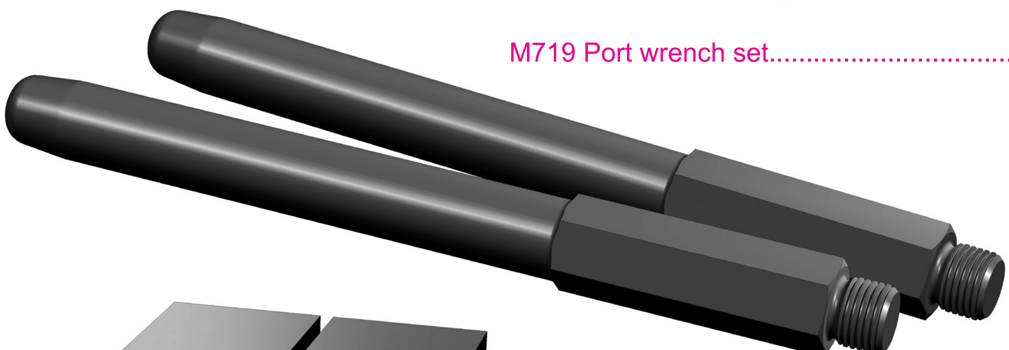
Conventional hand tools: There are only four screws on the type CF rack, a pair each of #10-24 and 1/4-20 Torx® Button Head Cap Screws, which have T25 and T27 sockets. In addition to the common “L” style wrenches, Ball Torx® drivers with screwdriver handles are *extremely* convenient, and reduce a servo swap to about five minutes. Torx® sizes are avalable from just about any supplier of professional tools anywhere in the world.

The servo has twelve #10-24 Socket Head Cap Screws which take either a 5/32 or 4mm hex key (“L” wrench), and one 1/4-28 screw in the end of the input shaft, which takes a 3/16 hex key. These are used only for servo disassembly. No standard automotive mechanic’s tools are needed to service the rack.

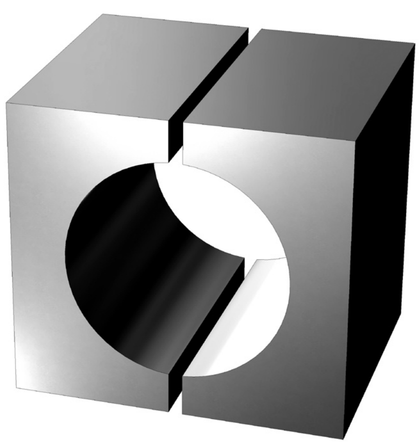
Special tools: The following special tools are available as the complete set or individually. In the case of the bullet sleeve (which has an .005” wall and will be ruined if dropped on the floor) a drawing is included for making copies.



M600 Hook spanner set 61.60

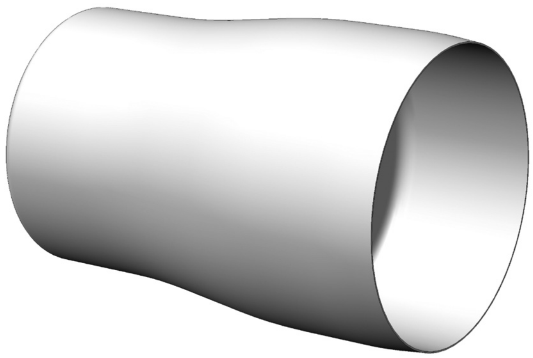


M719 Port wrench set.. 68.75

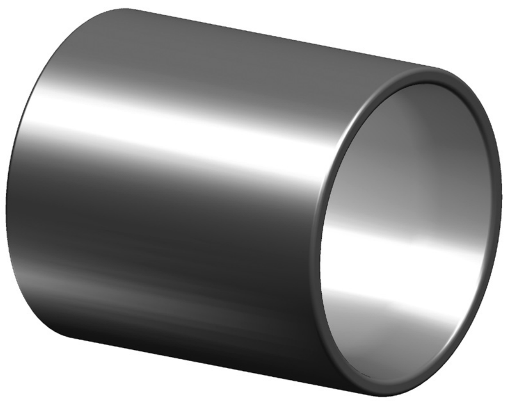


V175 Aluminum vise block set (for 1.75 bore cylinders)............. 73.75
V200 Aluminum vise block set (for 2.00 bore cylinders)............. 79.40

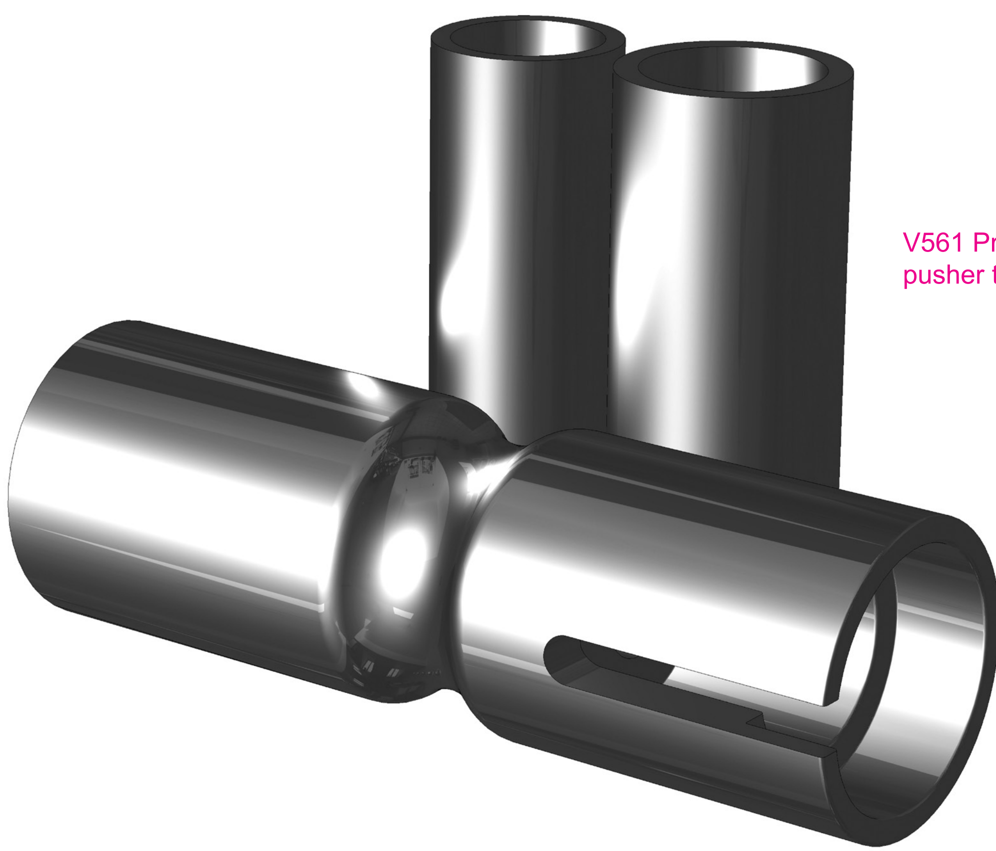
M720 Housing wrench... 45.25



V598 Spool seal mandrel 51.30

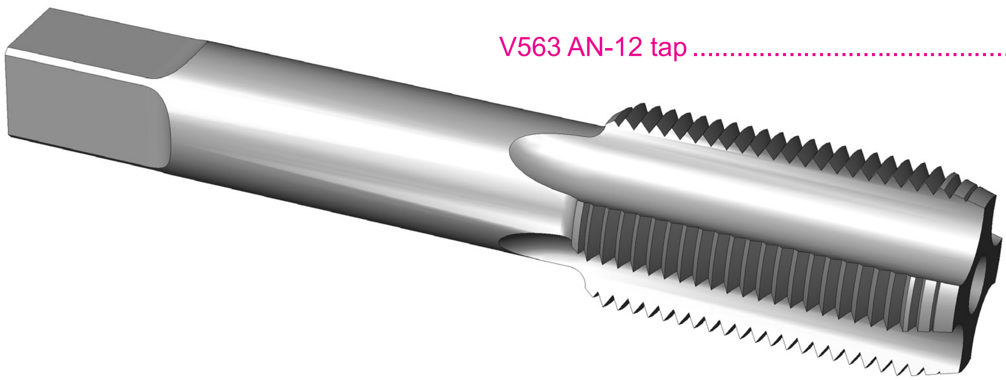


V599 Spool installation sleeve.. 62.25



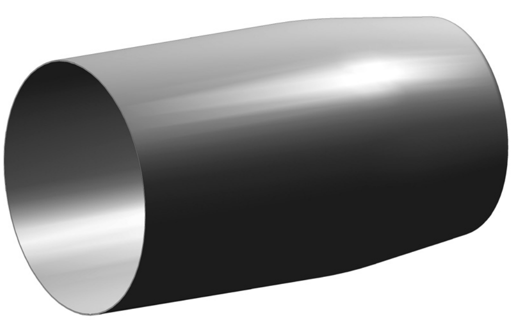
V561 Press receiver with bearing
pusher tubes......................... 187.75

V562 Bushing driver 52.55



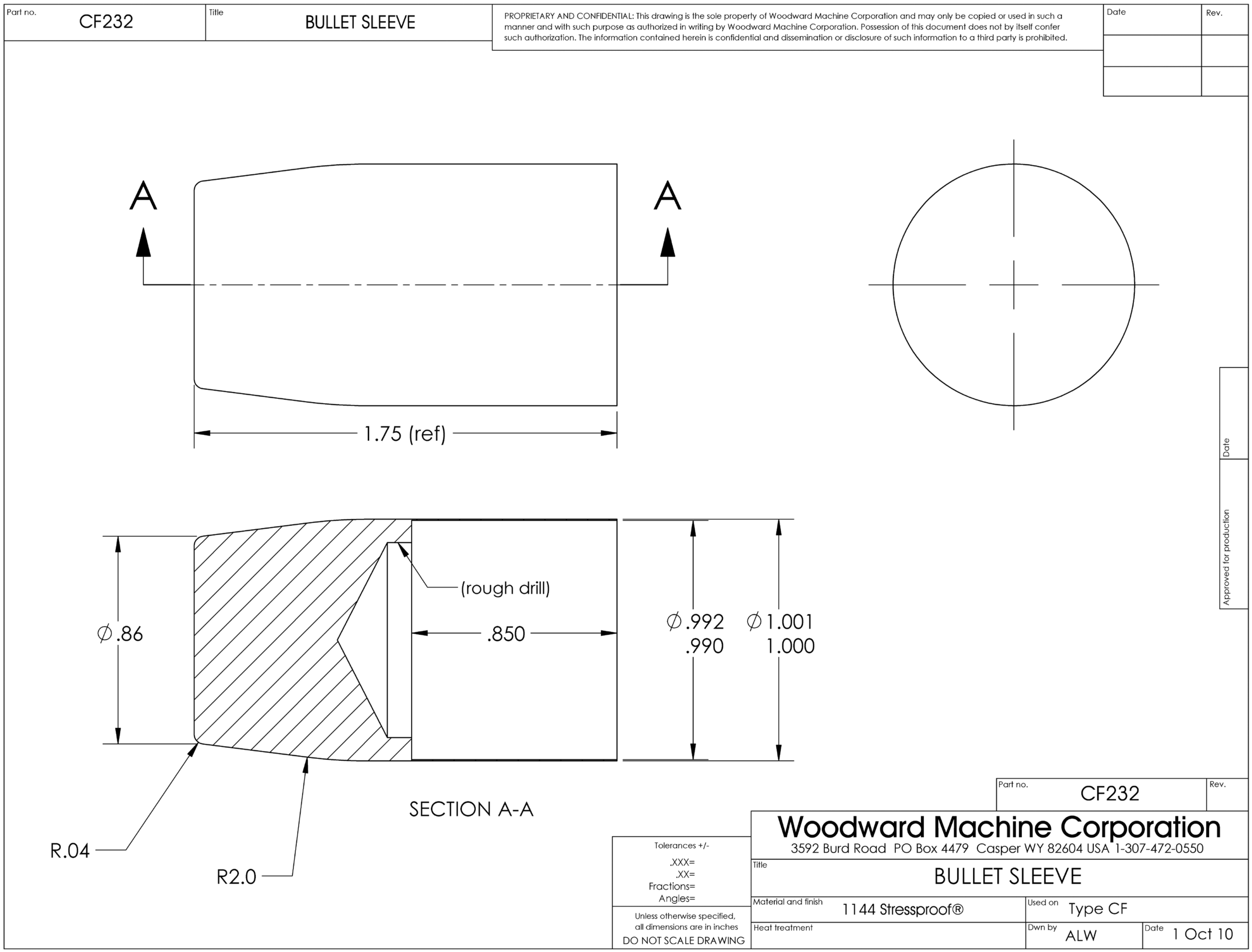
V563 AN-12 tap 98.82

V564 Knockout rod 21.25

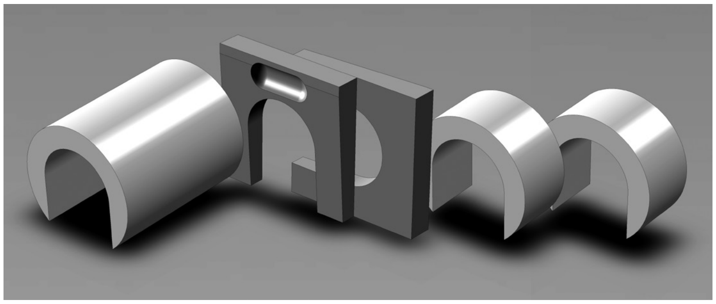


CF232 Rack thread cover (“bullet” sleeve)....................... 90.25
See drawing next page

Complete kit, includes all above tools (choice of V175 or V200)... 870.00


Part no.
CF232
Title
BULLET SLEEVE
PROPRIETARY AND CONFIDENTIAL: This drawing is the sole property of Woodward Machine Corporation and may only be copied or used in such a manner and with such purpose as authorized in writing by Woodward Machine Corporation. Possession of this document does not by itself confer such authorization. The information contained herein is confidential and dissemination or disclosure of such information to a third party is prohibited.
Date
Rev.
A
A
1.75 (ref)
Date
Approved for production
(rough drill)
∅.86
.850
∅.992
.990
∅1.001
1.000
R.04
R2.0
SECTION A-A
Part no.
CF232
Rev.
Woodward Machine Corporation
3592 Burd Road PO Box 4479 Casper WY 82604 USA 1-307-472-0550
Tolerances +/-
.XXX=
.XX=
Fractions=
Angles=
Title
BULLET SLEEVE
Material and finish
1144 Stressproof®
Used on
Type CF
Unless otherwise specified,
all dimensions are in inches
DO NOT SCALE DRAWING
Heat treatment
Dwn by
ALW
Date
1 Oct 10

Appendix II: Setup tools



Wedge and Spacer Kit V415-3547-AT2 .... 83.00

Holding the steering rack centered while setting toe: In order to adjust the tie rods, the steering rack has to be securely locked in the middle of its travel. This tool can be used either in the car or on the bench with the rack in a tie rod presetting fixture. The parts consist of a long acetal spacer, two short spacers and a pair of hardcoated aluminum wedges. The long spacer is machined to 1.950, which is half the travel of the NextGen steering rack.

Although a new rack will be very close to the 1.950 dimension on both sides, a rebuilt rack that has had its cylinder replaced may have needed its tube shortened by the amount necessary to clock the hose ports. While their overall alignment is not particularly critical, both ports must be within 30° of vertical to prevent trapping air in the cylinder. The thread pitch is 20 TPI, which means that the cylinder end screws onto the tube .050 per full turn. For example, if when tightening the joint the port stops 60° short of vertical, the tube can be faced .008 to correct it; if 90° away it can be faced .012, and so on up to a maximum of half a turn or .025. If necessary to correct beyond .025, face the remainder off the other end of the tube.

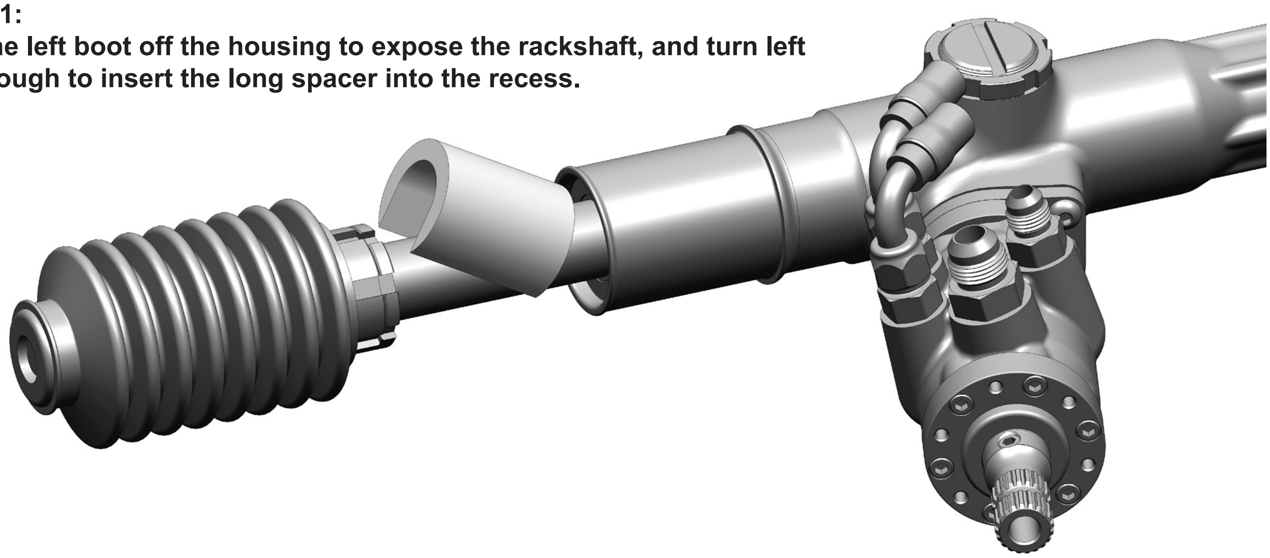
The rack is located in the chassis between two mounting clamps with a design clearance of about .040. Excessive clearance is removed by a shim. The chassis incorporates a plus tolerance between the mounting clamps while the rack incorporates a minus tolerance, thus ensuring that any chassis will accept any rack.

Since the left shoulder on the housing casting is fixed with respect to the pinion, it is the main locating feature and we recommend that it be solidly against the clamp. Any additional clearance resulting from shortening the cylinder should be shimmed on the right.

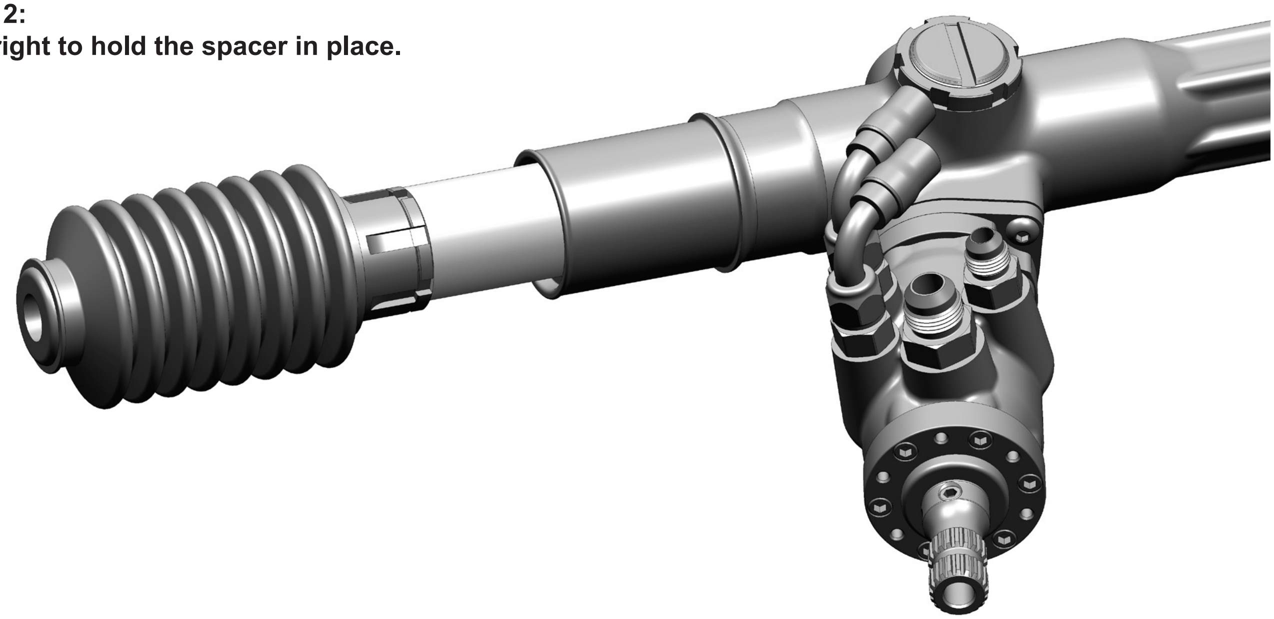
To achieve repeatability across an assortment of racks and chassis for toe setting purposes, two conditions must be met: the rack should always be butted against the same chassis mount and the solid spacer should always be used on the same side of the rack. The left side would seem to be the logical choice, although that is less important than doing it the same way each time. The illustrations show the long (solid) spacer used in the left side.

Note that the critical geometry of the rack—that is, the distance between its spherical centers—is not affected by variations in either the housing or the chassis.

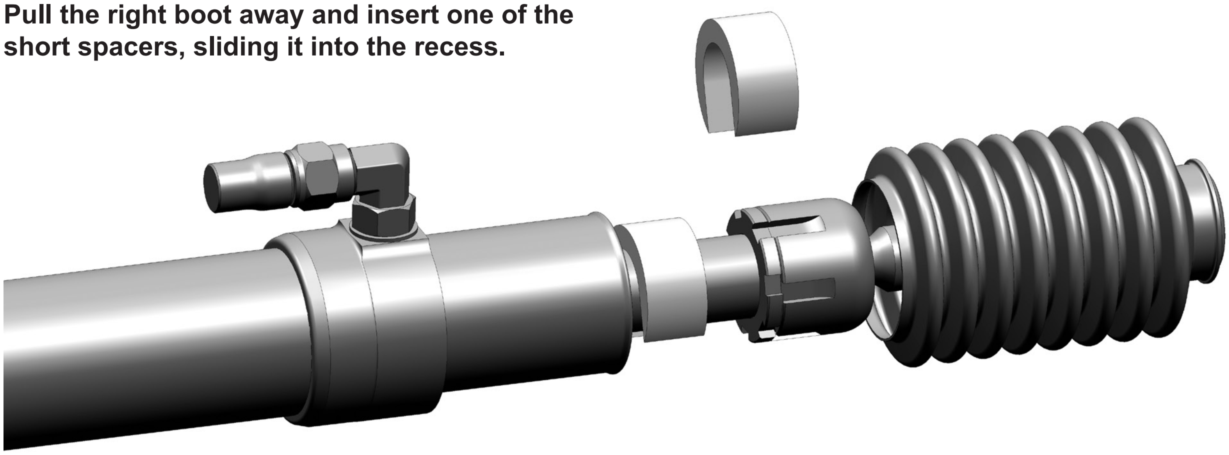
STEP 1:
Pull the left boot off the housing to expose the rackshaft, and turn left far enough to insert the long spacer into the recess.



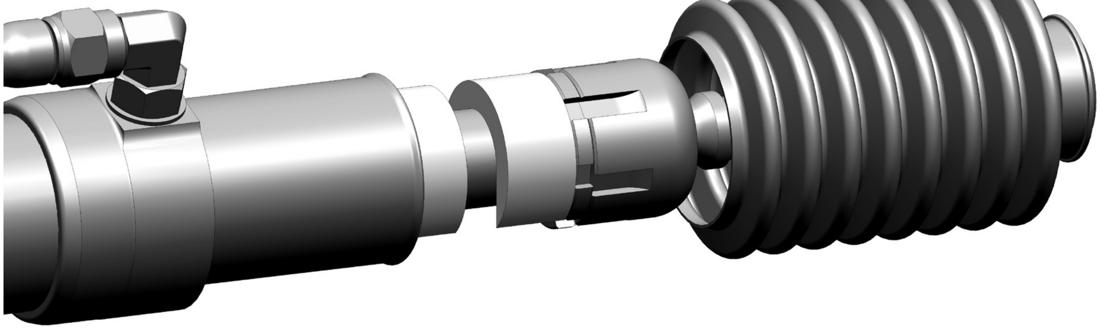
STEP 2:
Turn right to hold the spacer in place.



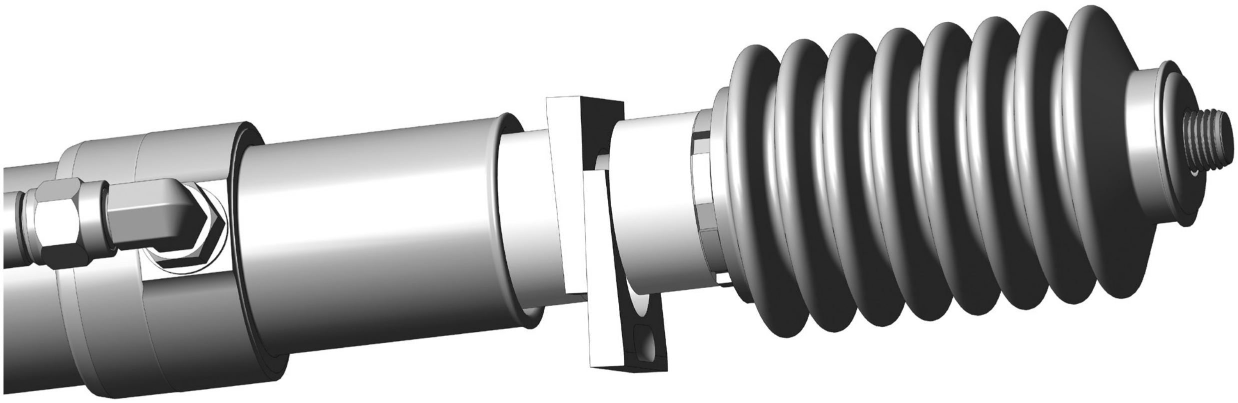
STEP 3:
Pull the right boot away and insert one of the short spacers, sliding it into the recess.



STEP 4:
Insert the other short spacer and slide it against the monoball.



STEP 5:
Insert the wedges from opposite directions with finger notches outward and squeeze them together.
Caution: very little force is required to lock the steering solidly.



Appendix III: Useful parts

It is possible in the Nextgen to reposition the front suspension attachment point fore-and-aft with respect to the steering axis. If adjusted off-axis beyond a certain point, some portion of the suspension load will be fed through the steering. In cases of large dynamic changes, *such as steering through the transition of a flat road course onto a high banked oval,* the additional downforce reacting through the steering linkage can cause violent oscillation. One effective countermeasure is to create back pressure within the steering rack, essentially turning the cylinder into a hydraulic damper.

The restrictor adapter is installed in the return port of the servo in place of the regular -8 hose adapter. **The orifice screws are furnished with a #39 pilot hole (.100 Ø) which is NASCAR's recommended absolute minimum.** The hole can be drilled out up to .218 Ø (limited by the 7/32 hex in the screw).

Return port restrictor fitting with interchangeable orifice
Return adapter including one screw-in restrictor orifice
V180-8-R 38.00

Extra orifice screws, each
V180-8-RB..15.00

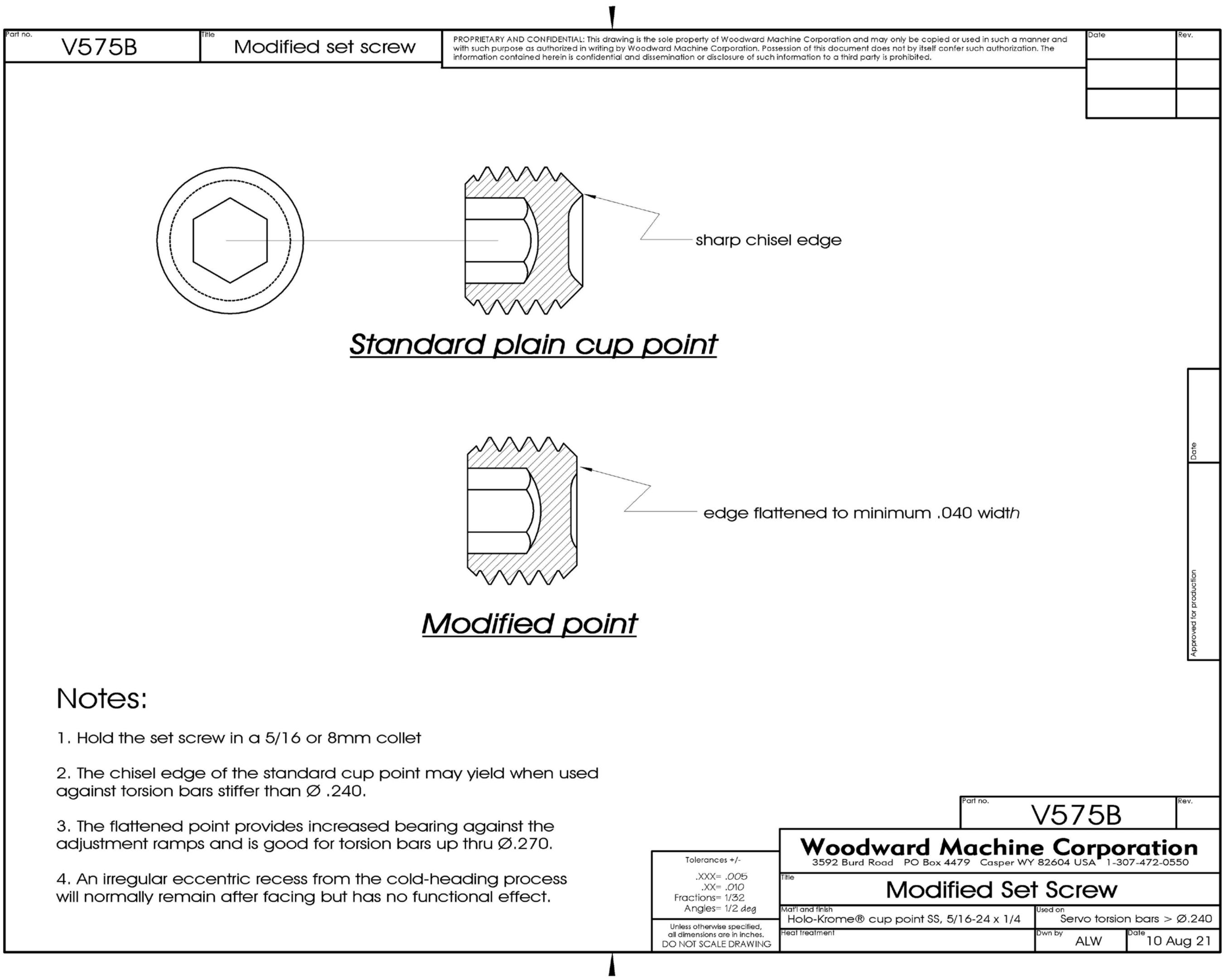
Note that restricting the return flow raises the back pressure within the cylinder and servo. The seals in the return side will withstand up to 1500 PSI—for example, connecting the pressure and return hoses backward won't damage it, unlike an OEM rack which will be blown—but, as a general rule, it is not advisable to exceed 300 PSI back pressure. The byproduct of back pressure is waste heat. Although the seals are good for 168 hours in Dexron III at 300°F, we recommend keeping the steering temperature below 275°. Note that with an unrestricted return and without the inevitable additional heat from the engine, the steering itself will rarely exceed 200°F.

The power steering cooler previously used exchanged heat with the engine coolant, which defeats the purpose because the engine typically runs much hotter than the steering. Because of this, the power steering cooler in the Next Gen is now an open component. Note: The newly approved Big Bore Kit reduces the required pressure, which lowers the operating temperature by at least 10° F.

Like increasing the back pressure, using a **larger torsion bar** in the servovalve stiffens the steering and can make the car less perturbable on a superspeedway, but the T-bar is retained in its adjusted position by set screws and the extra torque of a big bar can cause even a 40-42Rc set screw to yield. The torsion bar is the element that forces the valve to return to center, and if its centering adjustment becomes loose the valve will develop play and the steering will wander—the same effect as the familiar stretched hole in the torsion bar in a steering box. *In the type CF rack, an ordinary cup point is perfectly reliable to set the center (or bias) on bars up through .225 diameter but can be crushed at the point of contact by a .250 or larger bar.* The modification shown in the drawing below increases the contact area and lowers the unit pressure on the screw enough to permit the use of a .270 bar.

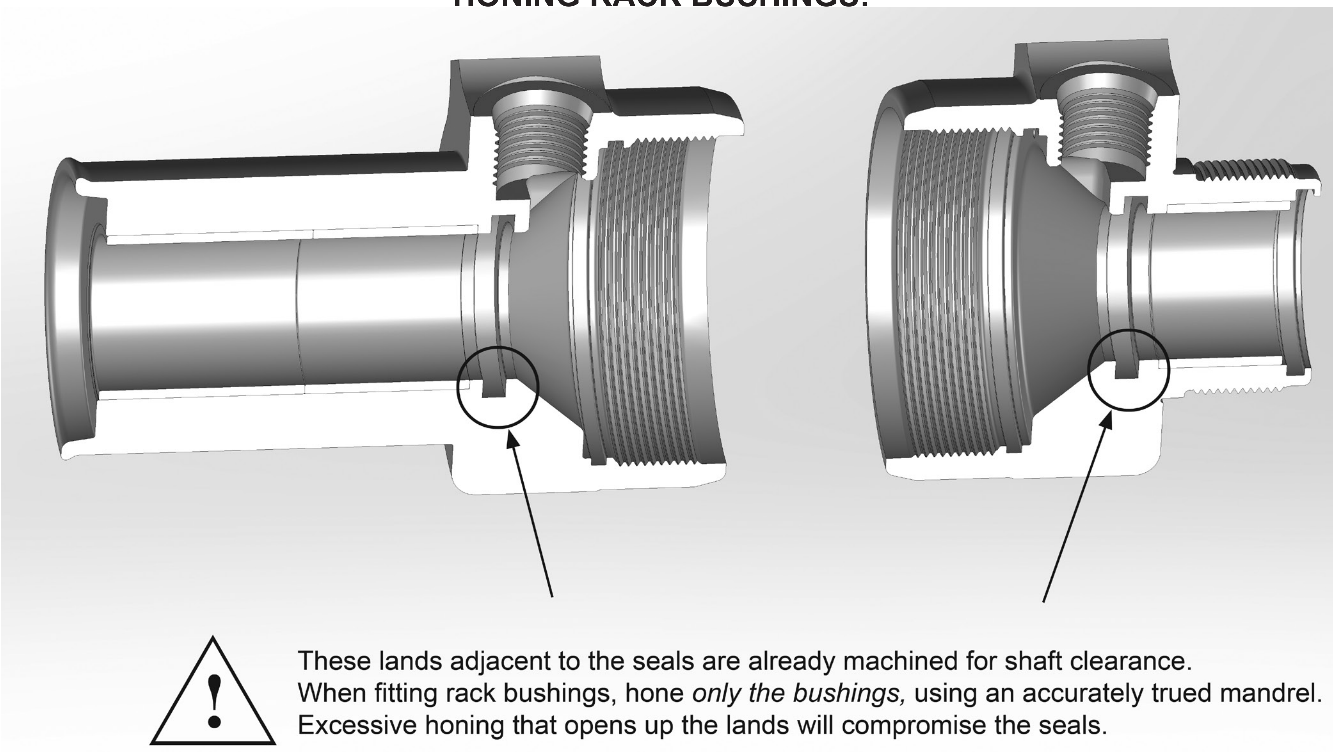
Once the valve has been adjusted to center (or offset, depending on the type of use) a wicking threadlocking adhesive such as Loctite 290 can be applied to the screws—but keep in mind that loosening of the T-bar is caused by the *load exceeding the screw's yield point* rather than simple loosening of the screw threads.

Both bias adjustment screws used on a Nextgen servo should be modified according to this drawing. Unbrako® or Holo-Krome® are used at the factory and are recommended; set screws from other sources may be less than 40Rc hardness.



Appendix IV: Big Bore Retrofit notes

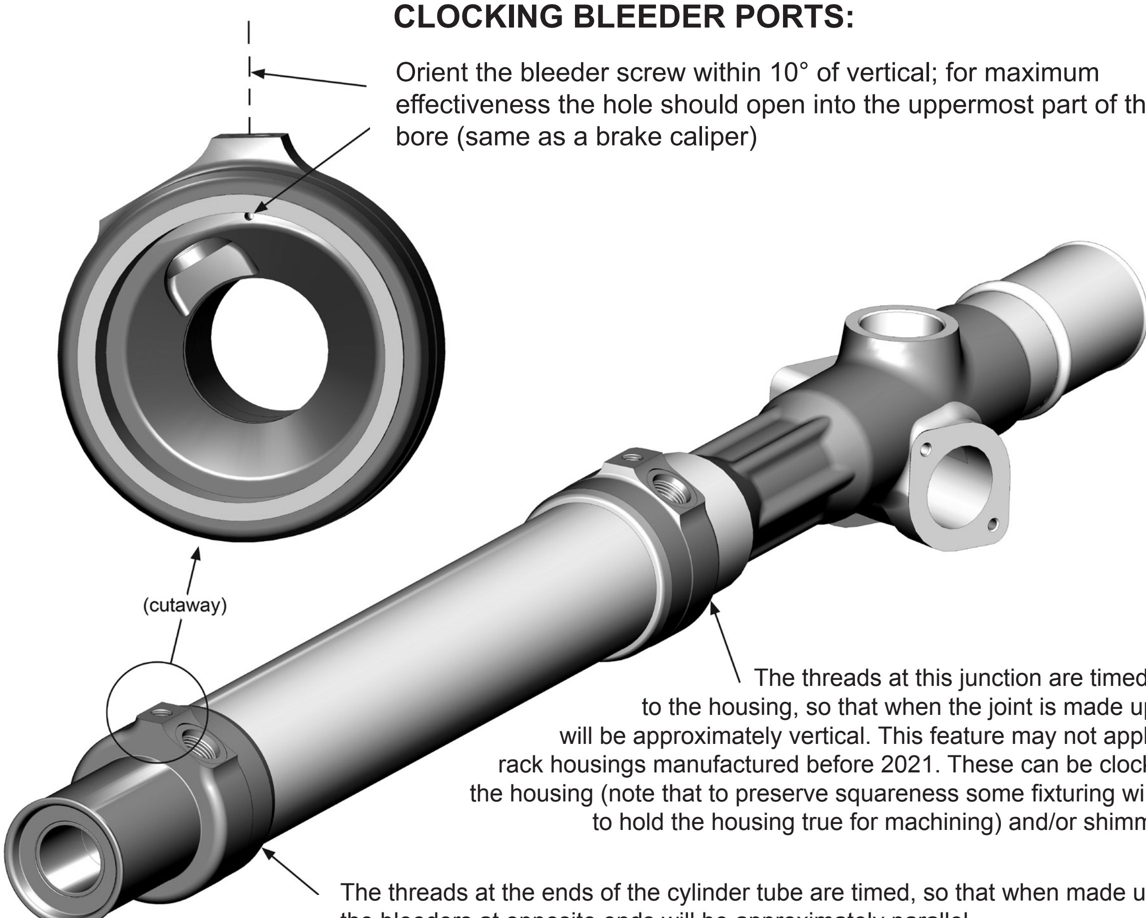
HONING RACK BUSHINGS:



These lands adjacent to the seals are already machined for shaft clearance.
When fitting rack bushings, hone *only the bushings,* using an accurately trued mandrel.
Excessive honing that opens up the lands will compromise the seals.

CLOCKING BLEEDER PORTS:

Orient the bleeder screw within 10° of vertical; for maximum effectiveness the hole should open into the uppermost part of the bore (same as a brake caliper)

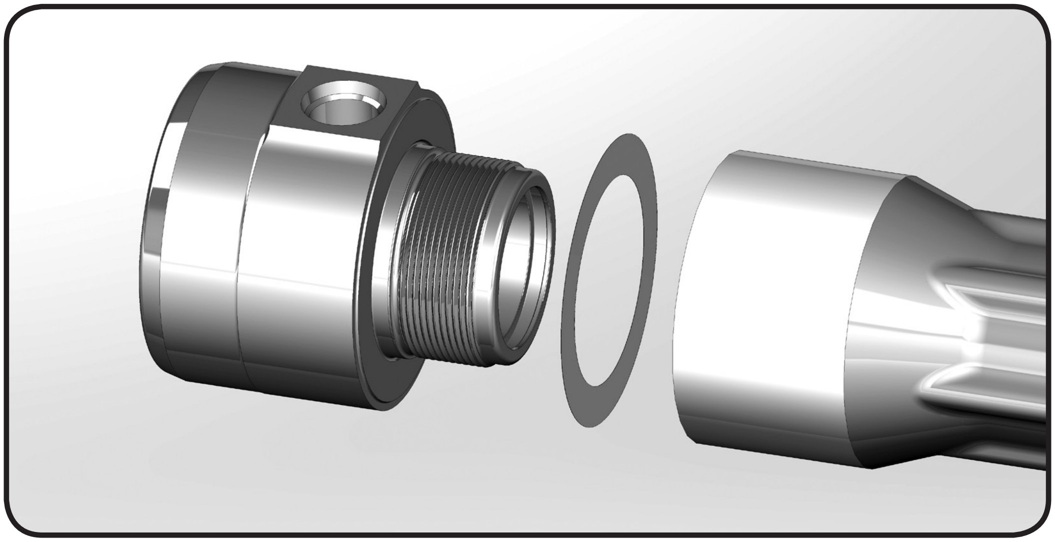


The threads at this junction are timed with respect to the housing, so that when the joint is made up the bleeder will be approximately vertical. This feature may not apply to Nextgen rack housings manufactured before 2021. These can be clocked by facing the housing (note that to preserve squareness some fixturing will be required to hold the housing true for machining) and/or shimming the joint.

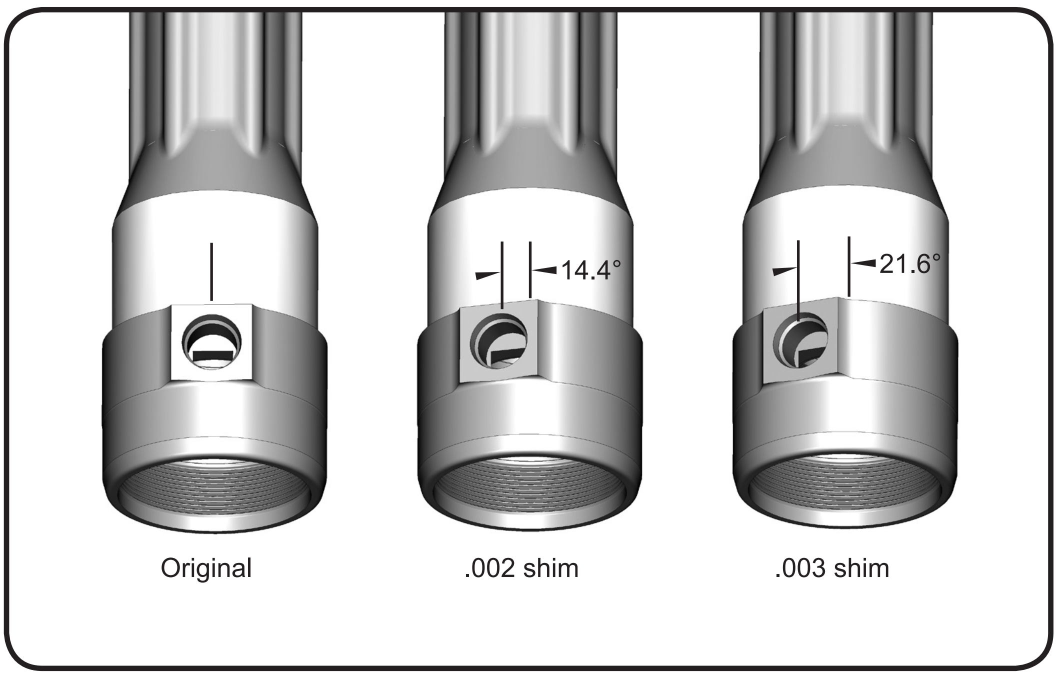
The threads at the ends of the cylinder tube are timed, so that when made up tight the bleeders at opposite ends will be approximately parallel.

CLOCKING CF151 PORT RELATIVE TO THE RACK HOUSING:

After a number of tightening cycles, the threaded joint between the CF151 cylinder adapter and the CF rack housing may migrate far enough beyond the desired vertical position to prevent self-bleeding. Its tightened orientation can be restored by inserting p/n CF151S-002 and -003, which are laser cut from brass shim stock.



The 1-20 thread pitch advances .050 inch per turn, or .001 inch every 7.2° of rotation.



The .002 shim will back the tightened position off by 14.4 degrees and the .003 will back it off 21.6 degrees. Nextgen rack housings have their threads timed, but CF racks from general inventory are not timed because the overall orientation of a given steering rack project is not known in advance, nor is the angle between its housing and ports. Correct clocking of custom and one-off racks is achieved by random trial assembly, with further adjustment by shimming or machining where necessary. When using shims, take care not to allow threadlocking adhesive to solidify on the shimmed interface before making up the joint.