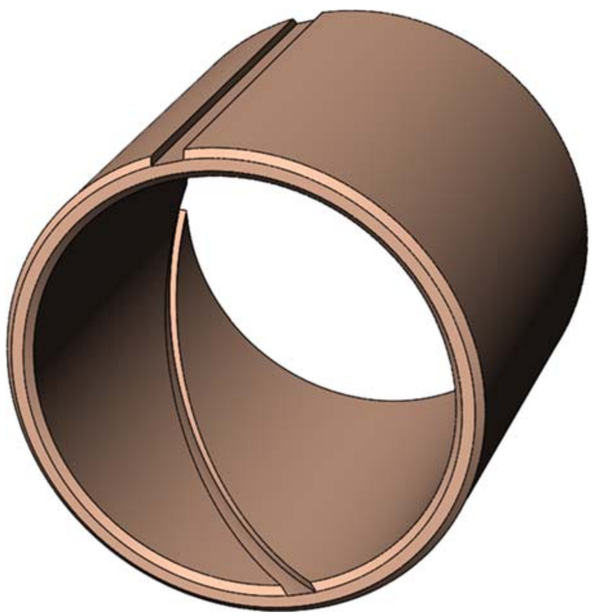
Chapter D15

Integral journal bearings



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Individual chapters of the Kalsi Seals Handbook™ are periodically updated. To determine if a newer revision of this chapter exists, please visit https://www.kalsi.com/seal-handbook/.

1. Introduction

This chapter provides experience-based guidance for designing the integral, machined in place journal bearing surfaces that are found on shaft guided pressure compensation pistons and laterally translating seal carriers that incorporate Kalsi-brand rotary shaft seals. The general principles are also applicable to other bearing locations in equipment such as mud motor sealed bearing assemblies and hydraulic swivels.

2. Journal bearing clearance

The objective of this chapter

The journal bearing found on shaft guided pressure compensation pistons (Chapter D14) and laterally translating seal carriers (Chapter D16) should fit the shaft closely so the component can follow lateral shaft motion, such as shaft deflection and runout. The ability of the component to follow lateral shaft motion:

- Isolates the rotary shaft seal from gross compression changes,
- Prevents seal and equipment damage related to metal to metal contact between the shaft and the seal carrier at the extrusion gap,
- Reduces high pressure seal extrusion damage by reducing runout-related fluctuations in local extrusion gap clearance, and
- Reduces third body seal abrasion when seal faces an abrasive environment by reducing the runout experienced by the seal.

In striving to have the journal fit the shaft closely, one must avoid shaft to journal binding that may occur due to component pressure breathing, differential thermal expansion, shaft deflected slope, tolerances, etc. This chapter is directed solely at avoiding such binding, while achieving a reasonably close guiding fit, and is not directed at optimizing journal bearing hydrodynamic performance. As such, this chapter is not a substitute for other journal bearing design publications. Extensive high-performance journal bearing design information is provided in the following books:

Mechanical Engineering Design, Fifth Edition (McGraw-Hill Publishing Company).

Machinery's Handbook (Industrial Press, Inc. New York).

Dimensioning to avoid binding

The steps that we recommend to avoid binding in applications where the shaft remains relatively parallel to the bearing are as follows:

1. Determine the basic shaft diameter S.

2. Determine the bilateral (±) tolerance of the shaft.

3. If a hollow bore of the shaft contains pressure, estimate the diametric outward pressure breathing of the outer surface of the shaft using FEA or (if appropriate) a closed form solution.

4. Estimate the diametric inward pressure breathing of the seal carrier, if any (Figure 1). This typically requires FEA to estimate, and is required for components that are immersed in a high pressure environment. (When a ring is immersed in a high pressure environment, the diameter changes because the outer surface of the ring has more area than the inner surface.)

5. Estimate the diametric differential thermal expansion between the shaft and journal bearing due to factors such as seal and bearing generated heat, etc. FEA (Figure 2) is recommended for this estimate, because the heat is not applied uniformly along the length of the components. (Manual calculations tend to over-estimate the clearance required to accommodate differential thermal expansion.)

6. Determine the bilateral (±) tolerance[1] of the journal bearing bore.

7. Determine the American National Standard RC 3 minimum diametric clearance (see ANSI B4.1-1967 (R1974 or **Machinery's Handbook**) for shaft diameter S.

8. Add Items 1-7 to determine the basic journal bearing diameter. This is a diameter that should not bind due to tolerances, pressure breathing and differential thermal expansion, assuming the shaft and journal bore remain parallel.

After completing steps 1 through 8, you may wish to review and refine the journal bearing design following the recommendations of the books noted on the previous page.

Binding across corners

Steps 1 through 8 do not prevent the "binding across corners" situation illustrated by Figure 3. The situation in Figure 3 may have negative implications, considering the forces and constraints imposed on the component that the journal bearing is a part of.

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1 Figure 12.11 of **Technical Drawing**, 7th edition provides a table of achievable total (bilateral x 2) tolerance related to various machining processes for various sizes of components (Macmillan Publishing Co., Inc. NY, NY: 19910).

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Calculate the maximum anticipated shaft slope through the journal bearing due to side load, shaft bearing clearances, etc. and evaluate the resulting clearance/interference in the worst anticipated combination of tolerance, pressure breathing, and differential thermal expansion. If shaft deflection exceeds the journal bearing clearance, the journal bearing may need to articulate to follow any additional shaft deflection. Such articulation is typically possible with pressure compensation pistons, but is not typically possible with laterally translating high pressure seal carriers.

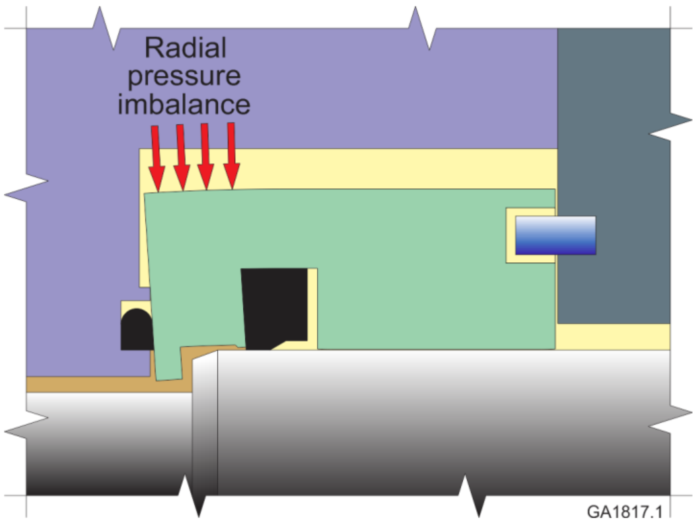

Figure 1

Deflection due to radial pressure imbalance of a laterally translating seal carrier

The portion of a laterally translating high pressure seal carrier that is located between the rotary shaft seal and the face seal experiences a radial pressure imbalance that causes an inward deflection of the seal carrier. This deflection has to be taken into account when designing the journal bearing fit, the extrusion gap fit, and the axial fit of the seal carrier with the surrounding support structure. This drawing depicts the deflection in exaggerated scale. In addition to the local deflection from radial pressure imbalance that is illustrated here, the remainder of the seal carrier will experience a certain degree of inward deflection because the area of the outer surface is greater than the area of the inner surface, and both surfaces are exposed to high pressure.

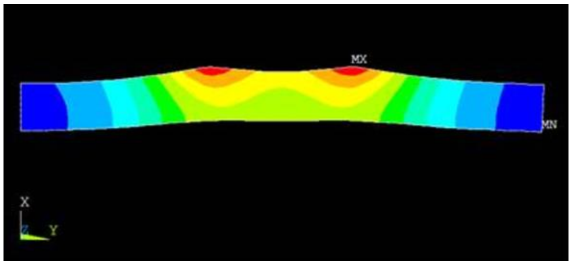

Figure 2

Use FEA to estimate shaft thermal expansion

This illustration shows deformation results from a thermal FEA representing two Kalsi-brand rotary shaft seals operating on a hollow shaft. The FEA shows that the cooler portions of the shaft constrain the thermal growth of the hottest portions of the shaft.

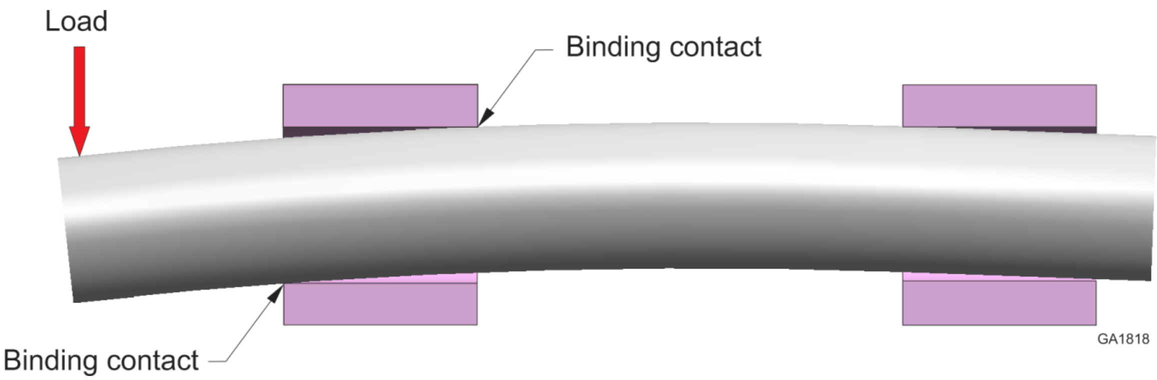

Figure 3

Binding across corners

Journal bearing clearance calculation steps 1 through 8 of this chapter do not prevent the “binding across corners” situation depicted here.

3. Pressure compensation piston journal bearing length

Avoiding the sticky drawer effect

To assure freedom of axial motion, the journal bearing length of a pressure compensation piston should be designed to avoid the “sticky drawer effect” described in Chapter D21.

Minimizing seal skew

In pressure compensation pistons, bearing length and clearance control the amount of seal skew that can occur with respect to the shaft (Figure 4). Since skew of a rotary shaft seal can cause abrasive wear, the journal bearing length of a pressure compensation piston should be long enough to minimize skew.

Designing for anticipated side loads

The journal bearing material and length must be selected to accommodate the side loads the component may encounter. In laterally translating high pressure seal carriers, the side loads include the breakout friction of the sliding seals, the effect of the piston weight, the torque reaction of the rotary seal, and the shoulder friction from any intentional axial hydraulic force balance. In mud motors, shaft deflection can be surprisingly large at the barrier compensation piston location, and the piston journal bearing can receive significant loads when the side loading causes it to contact the housing bore. In this sense, the barrier compensation piston serves as a deflection limiter which controls the maximum deflection experienced by the rotary shaft. This deflection limiting function helps to prevent metal to metal contact at the fixed location mud motor seal.

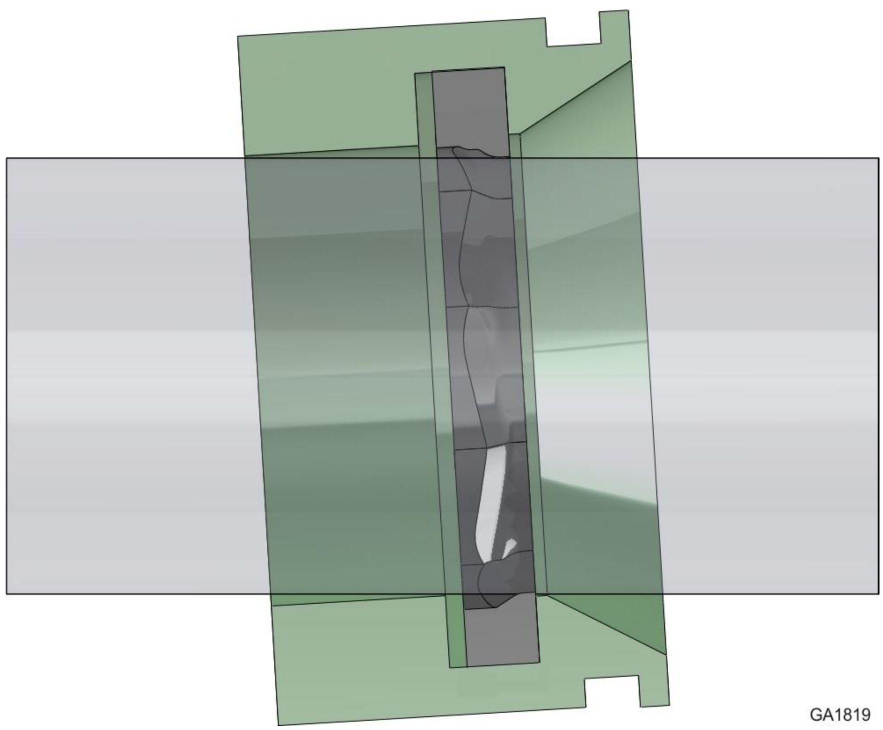

Figure 4

Short bearing length can cause undesirable seal skew

This image, which uses exaggerated bearing clearance, shows how a short journal bearing length in a pressure compensation piston can permit significant skew of the rotary seal with respect to the shaft. Such skewing accelerates third body wear of the seal if the seal is exposed to an abrasive environment.

4. Machine the bearing and extrusion gap bores in the same setup

Figure 5 shows a dimensioning and tolerancing method for journal bearing and extrusion gap bores that is useful on laterally translating high pressure seal carriers. On such carriers, the objective is to have as small an extrusion gap as possible, without risk of metal to metal contact between the rotary shaft and the seal carrier. The step dimension needs to be large enough to accommodate any shaft deflection or other shaft-to-seal carrier angular misalignment that can occur.

It is typically possible to lathe turn the journal bearing bore and the extrusion gap bore in the same machine setup, simply by jogging the cutting tool over by a few thousandths of an inch after making the finish cut on the journal bearing bore. This takes advantage of the natural accuracy of the lathe and assures nearly perfect concentricity between the journal bearing bore and the extrusion gap bore. The step dimension method of Figure 5 helps to helps to minimize extrusion gap clearance. This reduces pressure-related extrusion damage to the rotary shaft seal, while helping to avoid seal and hardware-damaging metal to metal contact between the shaft and the extrusion gap bore. It also eliminates costly to inspect extrusion gap diameter tolerance and diameter-dependent concentricity requirements. Use a dial test indicator or a height gauge to inspect the radial step dimension.

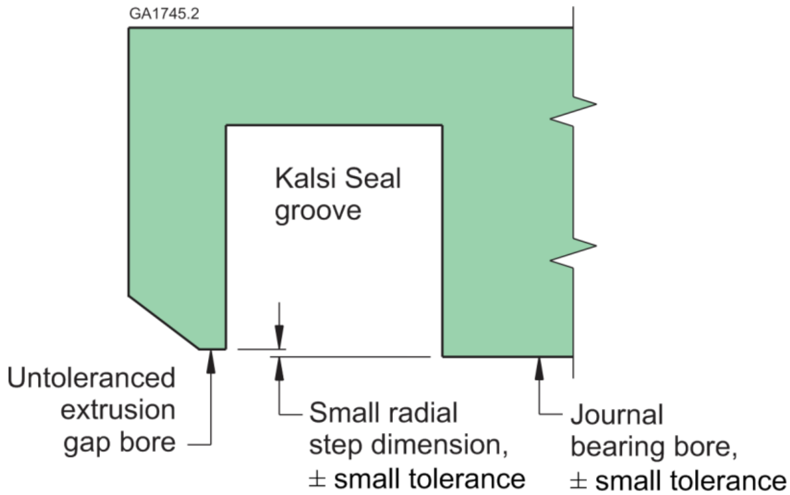

Figure 5

Extrusion gap dimensioning option for laterally translating seal carriers

In a seal carrier that is guided by a journal bearing bore, the extrusion gap bore and the journal bearing bore can be machined in the same setup, and the extrusion gap bore can be defined by a radial step dimension and tolerance, instead of a bore diameter, bore tolerance, and a concentricity tolerance relative to the journal bearing bore. This takes advantage of the accuracy of the lathe and facilitates small extrusion gaps for high differential pressure service, while helping to avoid damaging contact between the shaft and the extrusion gap bore.

5. Journal bearing interference fit

Integral journal bearings can be installed in a steel housing using an interference fit, and then finish machined. This provides maximum shaft guidance by eliminating bearing mounting clearance. The interference fit typically involves heating the housing and cooling the bearing to create clearance at the time of assembly. Once assembled, the parts acquire the same temperature, restoring the intended interference fit.

With an interference fit, temperature related changes to the journal bearing bore diameter are largely dictated by the coefficient of thermal expansion of the steel housing — if enough interference is provided to retain interference at the coldest anticipated equipment startup temperature. This is a distinct advantage because the bearing clearance with the mating steel shaft remains constant regardless of temperature. If the interference fit is lost at the coldest anticipated startup temperature, consider providing a pin that prevents the journal bearing from spinning relative to the steel housing.

6. Journal bearing edge treatments

For heavily loaded applications, the corners at the ends of the journal bearing bore should be broken or rounded to minimize edge loading. See Figure 6 for a corner treatment that has been successfully used to address edge loading in heavily loaded mud motor journal bearings. The mud motor was a research tool built by Kalsi Engineering to gain firsthand information on actual downhole rotary shaft seal performance. The bearing material was highly leaded tin bronze (bearing bronze), Copper Development Association alloy no. C93700.

The edges of any journal bearing oil slots (Figure 7) need to be carefully deburred.

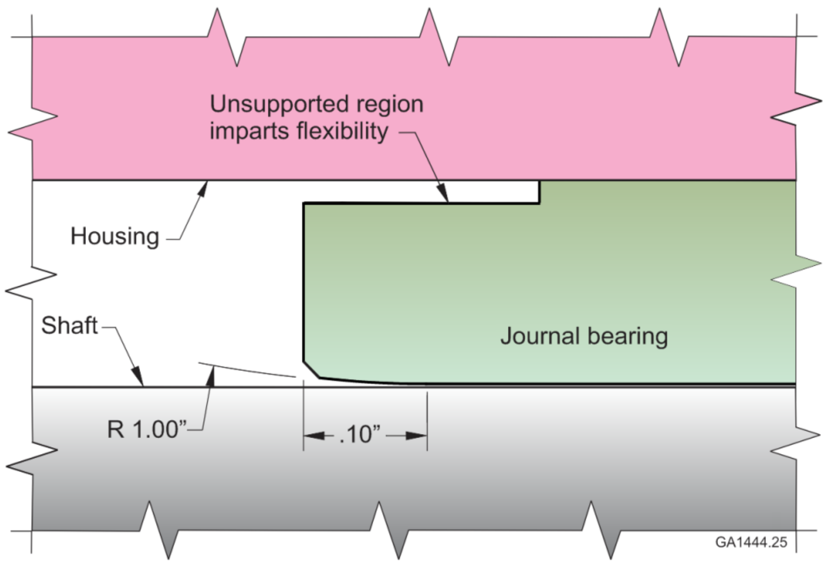

Figure 6

Journal bearing corner treatment to minimize edge-loading

The radius method and undercut method that are shown here have been used to minimize journal bearing edge loading in heavily loaded bearings in oilfield mud motor sealed bearing assemblies.

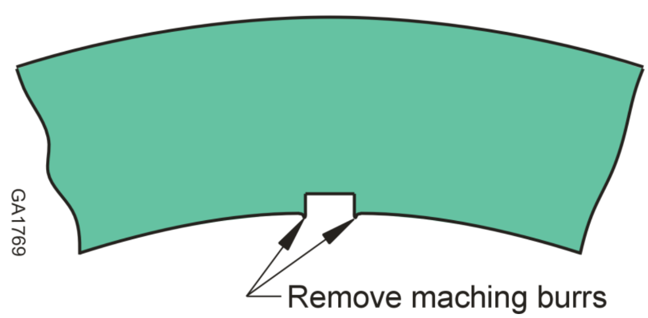

Figure 7

If the bearing has an oil groove, be sure that the groove is completely deburred

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Other thoughts on oil slots

It is imperative that the hydrodynamic edge of the Kalsi Seal™ be exposed to lubricant, and this is one reason oil slots or other oil passageways are sometimes used in pressure compensation pistons and other journal bearing implementations. Experiments have proven that with lower viscosity lubricants, an oil slot may not be absolutely necessary for lubricant filling purposes, provided that the seal ID, the bearing and the shaft are lubricated prior to assembly, a vacuum-filling procedure[2] is used to add the lubricant, and pressure is temporarily held on the lubricant after the lubricant filling operation to force the lubricant through the journal clearance and into the seal groove.

High viscosity lubricants, on the other hand, require higher pressure over a much longer period of time to drive the lubricant through a journal bearing clearance. A slot, or other lubricant communication means, may be desirable when high viscosity lubricants are employed, to ensure that lubricant passes through the journal bearing and actually reaches the Kalsi Seal during filling.

Expired U.S. Patent 1,156,700 teaches the use of journal bearing with a spiral oil slot combined with an axial flow port through the housing for circulation and cooling purposes (Figure 8). Shaft rotation pumps the lubricant through the spiral, and the lubricant flow returns to its starting point via the axial flow port. Such an arrangement would also facilitate getting lubricant to the Kalsi Seal during the filling operation.

The flow resistance provided by a closely fitting journal bearing may provide a significant benefit in applications where the rotary shaft seal is occasionally subjected to a sudden momentary pressure reversal. As the sudden pressure pulse hits the seal, the lubricant may not be able to escape rapidly through the journal bearing clearance and may therefore support the seal against pressure pulse-induced deformation and axial shuttling. This theoretical benefit requires investigation before it can be confirmed.

2 Several manufacturers provide commercial vacuum lubricant filling systems. Some systems have heaters to reduce the viscosity of high viscosity lubricants, for ease of filling.

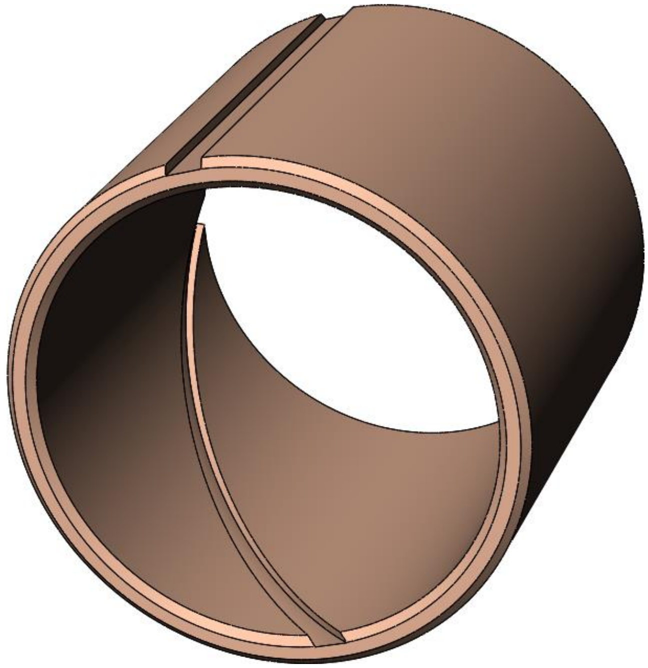

Figure 8

Spiral oil groove with axial return slot for shaft-driven lubricant circulation.

7. Materials for integral journal bearings

Although our experience with integral journal bearings is not extensive, from time-to-time we are asked for material recommendations.

We successfully used CDA[3] C93700 as a radial bearing in an oilfield mud motor that we built for R&D purposes during a DOE[4] sponsored SBIR[5] project. The bearing ran on a ground tungsten carbide coated portion of the mandrel. We successfully used C93200 for the journal bearing portion of a pressure compensation piston of the same mud motor. Other copper-based bearing materials are known to have better compatibility with hydrogen sulfide and calcium chloride.

We have successfully used UNS C72900 AT90 (preferred) and C72900 AT110 for the journal bearings of laterally floating steel seal carriers, and for small diameter floating backup rings. In all cases the journal bearing ran on a ground tungsten carbide coated surface. As a material for small diameter floating backup rings, we prefer C72900 over many other bearing materials because it has a higher modulus of elasticity, which reduces

3 Copper Development Association.
4 Department of Energy.
5 Small Business Innovation Research.

pressure-related deformation. C72900 is also easier to machine than those bearing materials that do have a comparable modulus.

If you elect to use beryllium copper as a journal bearing material, be aware that beryllium copper ranges from ductile to very brittle. Select a grade and heat treat that provides ductility.

In sealed roller cone drill bits, one journal bearing arrangement is a silver-plated steel bore running on Stellite.[6] Special techniques are used to ensure adequate adhesion of the silver plating. These techniques are well known by the platers in the environs of Houston, Texas who routinely deal with oilfield companies.

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6 Stellite is a trademark of the Deloro Stellite Company.