

Jewel Bearings Solve Light Load Problems

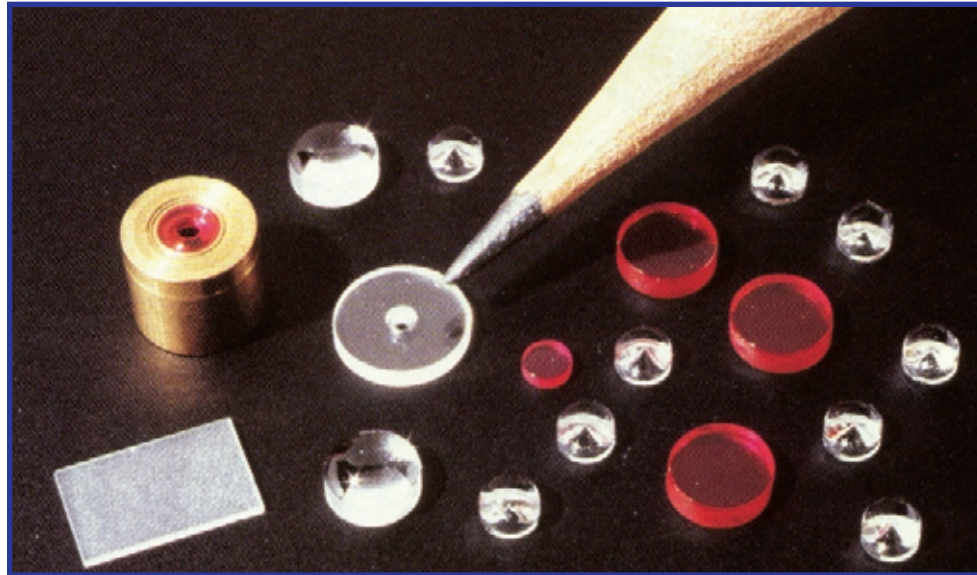
These miniature bearings are unsurpassed for low breakaway friction, long life, and resistance to harsh environments.

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Jewel bearings earned their reputation as reliable low-friction devices by keeping watches and timepieces working accurately, some for over a century. In low-load and low-speed applications, they remain unequalled as maintenance-free bearings in precision analog movements such as altimeters and guidance systems. Furthermore, advances in crystal growing and manufacturing now make the bearings cost-effective alternatives to conventional bearings in selected applications. Ruby, sapphire, and hard glass make the best jewel bearings because they are hard and take a near-perfect polish, down to 1 or 2 μm . While diamond holds promise as the ultimate jewel bearing because of its extreme hardness and low friction, its high cost makes it unacceptable.

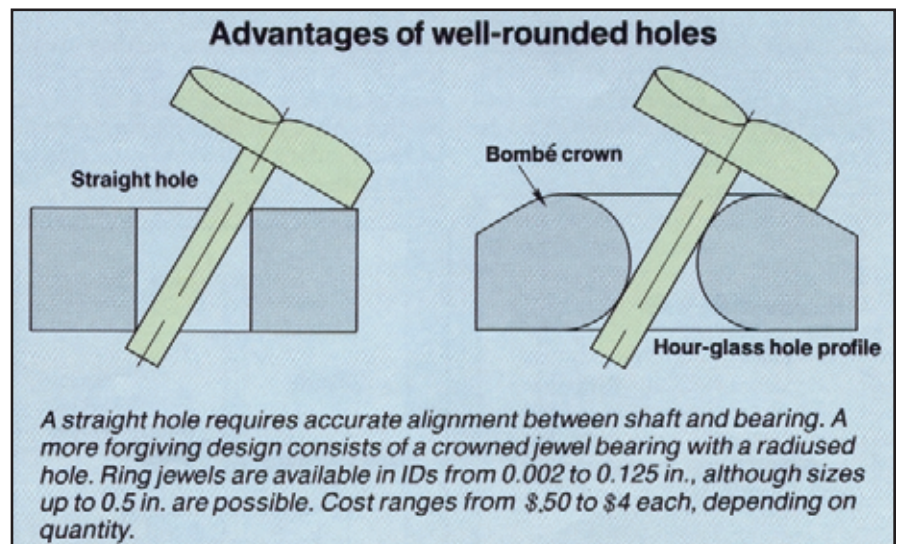
Jewel bearings perform best when loads are less than 500 g and when constant speeds are low or momentary at higher rates. Within this realm, the bearings compete with miniature ball bearings, flexural pivots, taut-band suspensions, and a variety of low friction materials such as Teflon. the most com



Clear sapphire, red rubies, and hard glass make ideal miniature bearings for low-torque, low-speed and light-load applications such as compasses and sensitive analog meters. The same machining techniques that produce the bearings provide precision orifices for use in flame-off torches, miniature check valves and air bearings.

mon jewel-bearing designs are rings or journals, cups, Vs, balls, rollers, and endstones. Other features the bearings offer are:

- Low friction coefficient. For steel on sapphire. C_f is 0.1 to 0.15. Breakaway torque is so low that a jewel bearing recently was used in a mechanical torque meter sensitive





The cone V-bearing allows the pivot some radial freedom while keeping it centered. The bearing may be used vertically or horizontally. The V-block involves greater friction but carries higher load. It is used in scales and balancing mechanism with a knife edge riding in the V.

MICRO-DRILLED INSERTS



Orifices sizes as small as 20 $\mu\text{in.}$ are possible, and sizes from 0.002 to 0.02 in. are readily available, as are different hole shapes.

enough to measure the thrust produced by a fruit fly.

- High hardness. Sapphire has a compressive strength of 300,000 psi (2,000 knoop).

- High temperature stability. Melting point is about 2,050° C.

- Low relative cost. Typically, a jewel bearing costs 20% as much as a ball bearing and 10% as much as a flexural pivot.

- Tight concentricities, to 0.0002 in. in most cases.

- Small sizes for compact designs. Shafts can be as small as 0.006-in. diameter, but more typically range from 0.02 to 0.125-in. diameter.

Ring jewels

These are journal or annular bearings commonly found in instruments such as watches, dial indicators, and gimbal suspensions. Because of their manufacturing method, ring jewels offer a feature

not available in conventional bearings. The hole is contoured like an hourglass or olive shaped, rather than a straight cylindrical bore. The advantage is reduced contact area, hence, lower friction between shaft and bearing.

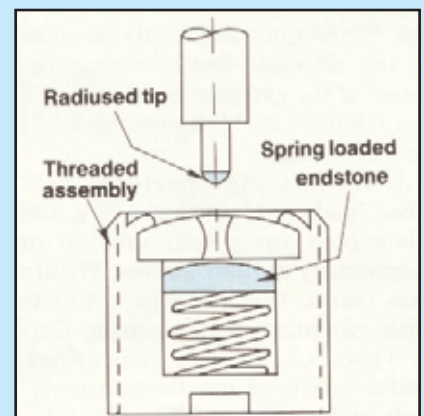
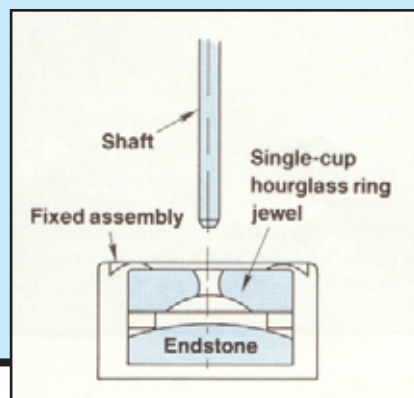
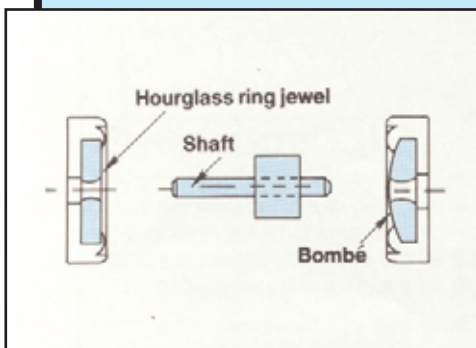
The hourglass profile also allows a degree of radial freedom in the bearing. If the shaft becomes misaligned, the hole shape prevents binding. Also, it allows closely fitting the shaft to the bearing; diame-

MOUNTING JEWEL BEARINGS

The simplest jewel bearing is a journal-like ring. The hole may be cylindrical, but rounding the sides to an hourglass shape allows for shaft misalignment without binding. A rounded surface on the bearing face, called a bombé, enables the bearing to handle thrust loads as well.

Greater thrust capacity results from mounting an endstone below or behind a single-cup, olive-hole ring jewel. The endstone has a radiused surface, like a bombé, but without a center hole. This arrangement is not suitable for shock loading. Also, the fixed assembly must be held in place with a retaining ring or other device.

For shock loads, an endstone can be spring loaded below a bombé or ring jewel. The stepped shaft and bombe carry thrust loads. The threaded assembly is another method for securing the jewel bearing.



AND ORIFICES

The development of lasers that could bore pinholes in sapphire was followed by flood of new products that were held back by the lack of small precision orifices. Ink-jet printers and miniature extrusion dies are among the developments taking advantage of these orifices. Other competing micro-drilling techniques such as EDM, photoetching, and ultrasonic milling cannot match the precision of a jeweled orifice.

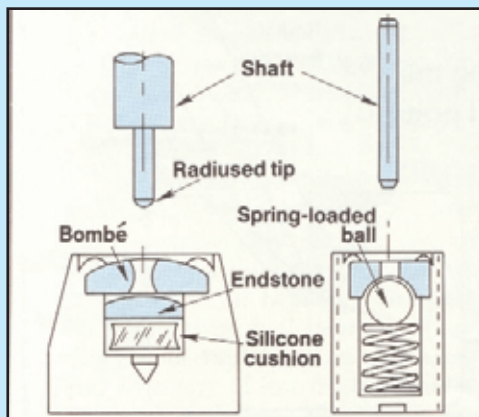
The orifices have no burrs or irregularities because the jewel is first pierced with a laser and then opened by a charged diamond-wire lapping process. Hole-roundness tolerances are 0.0001-in. TIR, and lapped surfaces can have sharp edges. Because several thousand holes can be lapped at a time, variation from part-to-part is negligible.

tral clearances of 0.0002 in. or better are possible.

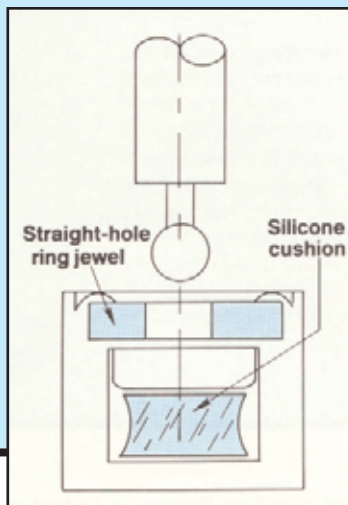
V and cup bearings

These bearings are most often made of hard glass and sapphire, which have among the lowest friction coefficients of all miniature bearings, about 0.12 for steel-on-sapphire. Cup and V-bearings are used in sensitive magnetic meter movements, compasses, encoders, turbine flow devices, and gal-

Other shock mounting techniques include a silicone cushion behind the end-stone or a spring loaded ball. The spring is used for light shock loads, and the silicone for higher shock loading, up to 1,000g.



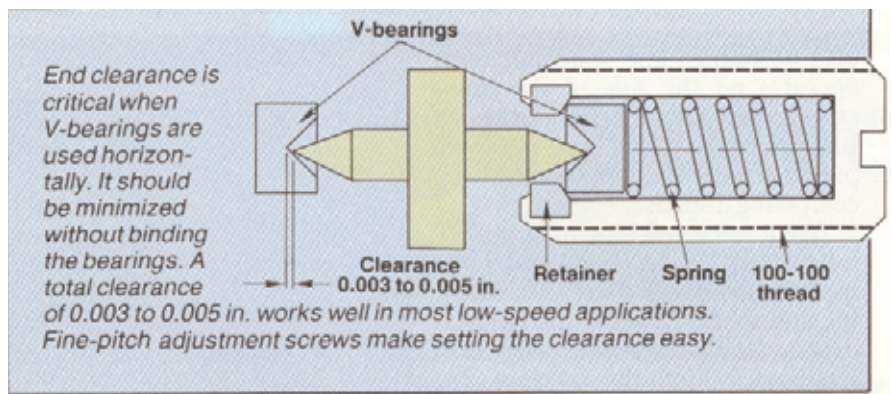
Mounting a ball on a shaft allow higher thrust loads than just a rounded shaft end. The silicone cushions shock loads, and the straight-hole ring jewel carries loads normal to the axis.



vanometers.

The low-friction coefficient is due largely to the moving shaft's near point contact on a V-bearing. In contrast, other miniature bearings use line contact. Also, glass and sapphire deform less under load than competing materials. This property keeps friction and torque nearly constant over the life of the bearing. Wear is usually found on the pivot or shaft rather than the jewel. The amount of wear usually depends on load, speed, and shaft material.

Glass V-bearings have slightly lower friction because their surfaces are fire polished. Surprisingly, some compass manufacturers add a small drop of lubricant to the glass V-bearing to damp compass card oscillations, which otherwise would continue for long periods. A fire-polished surface minimizes the asperities, hence, the lubricant provides viscous damp-



ing to the shaft. This is not a problem with sapphire V-bearings, which have microscopic, drag-producing asperities on their lapped surfaces.

The effects of friction producing asperities are especially evident when a V-bearing is used horizontally. In this position, the bearing has higher load bearing capacity. However, the mating conical shaft tries to roll up the surface of the V-

SEEING CLEARLY THROUGH SAPPHIRE

Optical-quality sapphire has five times the resistance of carbide to scratches and chemicals. Because it is next to diamond in hardness (9 Mobs vs. 10 for diamond or 1,800 to 2,200 Knoop) sapphire lenses work well on barcode readers, watch crystals, and other devices with moving lenses. High strength and a moderate refractive index also make sapphire a good selection for high-pressure windows and view ports.

Sapphire is unaffected by acids even at 1,000C. It is virtually inert to all reagents and alkalis at room temperature, including hydrofluoric acid. Furthermore, sapphire exhibits good infrared transmission across a wide spectrum of wavelengths, and is used in infrared detectors and filters.

The mineral's high-temperature conductivity, strength, and stability make it ideal for high-energy laser applications. Sapphire pinholes and apertures typically outlast those made of metal. The crystal's availability and low cost make it an excellent material for high volume use. For example, a 1-in. diameter watch crystal costs from \$10 to \$12.

bearing radius, and the shaft end operates on the side of the cone rather than at the point of the V. Like the ring jewel, the V-jewel provides more radial freedom than competing designs.

When a V-jewel is used horizontally, a 0.003 to 0.005-in. clearance must be maintained between bearing and shaft. To make the adjustment, fine-pitched screws are mounted behind the bearings. In this arrangement, turning a 100-100 (100 threads/in.) screw once, for example, produces linear travel of 0.013 in. After gently tightening, backing the screw off one-quarter turn easily produces the clearance. Threaded screws that work best for adjusting end-play are the 2-80, 100-100, and 4-90 sizes.

Sizing the radii

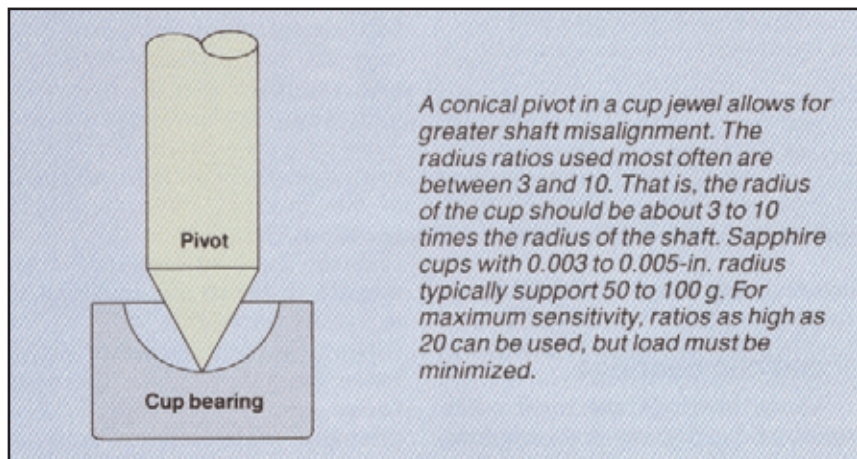
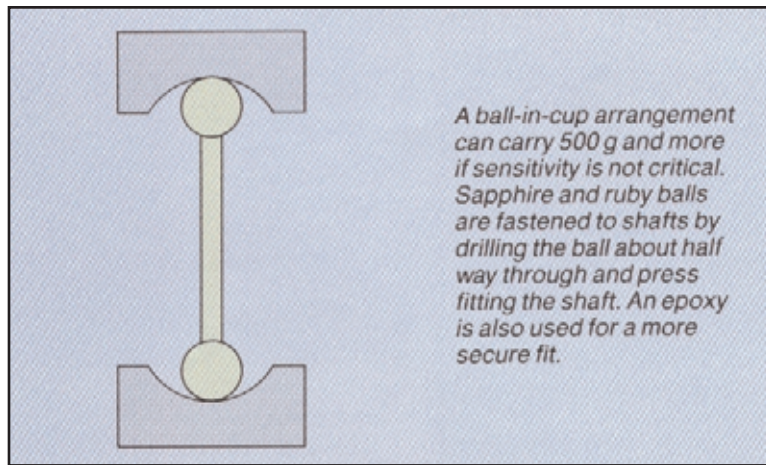
Load-bearing capabilities and friction are governed by V-bearing or cup size, and cone radius. Generally, the V-radius should be three times the radius of the pivoting member. This allows room for the pivot radius to wear in and conform to the V-radius without binding.

Best performance results when the conical V-angle is 85° and the conical pivot angle is 55°. Typically, glass V-bearings with minimum radius points tolerate loads to 200 mg. Larger points handle higher loads.

As shaft radius decreases in a bearing, friction and load carrying capacity also decrease. The small contact radii produce large contact stresses.

High hardness can be a detriment for a jewel bearing because they can fracture under high impact loads or high vibration. The bearings are not recommended for shock applications unless they are properly mounted with a spring or silicone pad to absorb damaging vibration. Some examples are shown in the box Mounting jewel bearings.

Pivot material also deserves attention. Nickel chrome and 420 stainless-steel alloys are good choices for pivot and shafts. Generally, hardness in excess of R~ 50 and surface finish of 2 to 4 μin is recommended. Nickel-chrome alloys of-ten are preferred because they are corrosion resistant, non-magnetic, and have a hardness over R~ 65.



PICKING THE RIGHT RADIUS

V-jewel and cup bearings work best with minimum contact between the pivot (shaft end) and jewel. The design rule-of-thumb is that bearing radius should be about three times pivot radius.

If the radius ratio is less than three, friction increases and movement becomes uneven. Too high a ratio — that is, a point-like pivot — results in excessive sensitivity, poor damping and repeatability, and susceptibility to damage in handling.

Material selection is usually based on load, operating conditions, and cost. Sapphire is used when the assembly is solidly mounted and movement weight exceeds 0.2 g. Glass V-jewels have lower friction and cost, and are recommended when the load is less than 0.2 g. Bearing diameters typically range from 0.04 to 0.125 in. A 40-g load on a 0.05-mm radius produces a stress of 1,237 kg/mm². But increasing the radius to 0.8 mm reduces stress to 131 kg/mm².

In vertical applications, the optimum radius of a V-bearing is about three times the pivot radius. Glass jewels work best when the supported load is less than 0.2 g. Sapphire is used when the supported weight is greater than 0.2 g.

