

## Shaft Design Considerations in Ferrofluid Vacuum Rotary Feedthroughs

Walter Helgeland  
Technical Director

Rigaku Americas Corporation • Innovative Technologies • 7A Raymond Avenue, Suite 4 • Salem, NH 03079

T: 603-890-6001 • F: 603-890-6016 • I: info@Rigaku.com



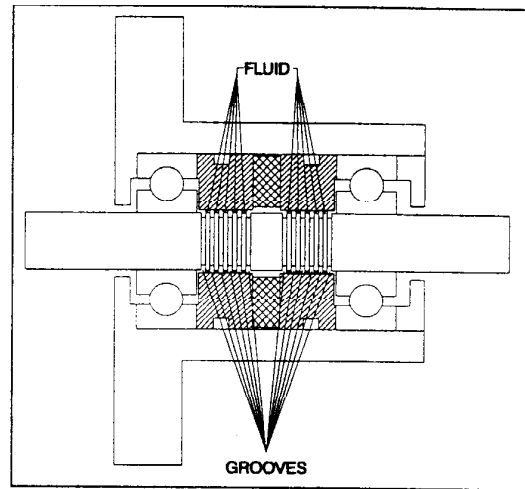
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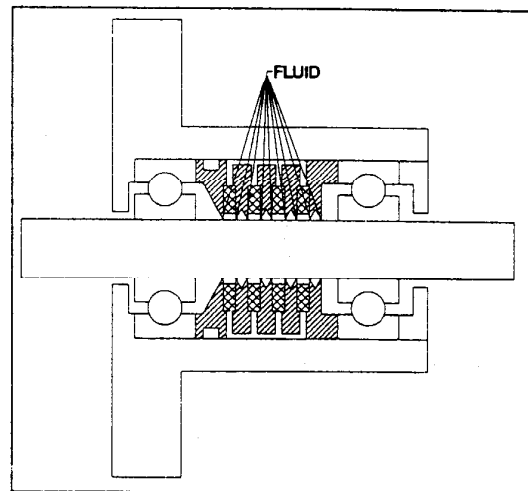
**Abstract:** Ferrofluid-based vacuum rotary feedthroughs are widely used. Design details and material selection have great impact on the strength and stability of the shafts in these devices. Grooves weaken shafts. The common multiple-groove design leads directly to a substantial reduction in shaft strength and stability. Feedthroughs using ungrooved shafts and superior steel alloys are available from Rigaku/USA.

### Background

Ferrofluid-based vacuum rotary feedthroughs employ a series of magnetic fluid rings in an axial array along the rotating shaft to provide a multi-stage seal between the vacuum chamber and the atmosphere. Each fluid ring can only support a pressure difference which is less than one atmosphere, so the total pressure differential must be spread over a number of stages. The magnetic circuits in these devices must ensure that a series of separate high-flux regions are created in the sealing gap around the shaft. The earliest commercial versions of these devices, known as "Ferrofluidic<sup>®</sup>" seals, accomplished this by using grooves (typically 0.030 inch wide x 0.030 inch deep) in the shaft (made of 416 stainless steel) to subdivide a single magnetic circuit into several parallel circuits. This design is still in use today. (Ferrofluidic<sup>®</sup> is a registered trademark of Ferrofluidics Corporation.)



An improved design (U.S. Patent 4,605,233), developed by Rigaku Corporation, places no grooves in the shaft. The required magnetic field subdivision is accomplished in the magnetic system external to the shaft. As a result, the shaft is not weakened by grooves. A stronger material (17-4PH stainless steel) further enhances strength.

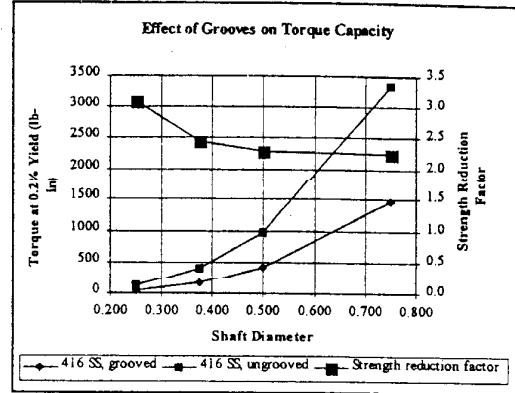


### Calculated Impact of Grooves on Torque Rating

In the absence of shock, impact, and rapidly reversing loads, the torque capacity of a shaft can be calculated in a straightforward manner for ungrooved shafts. Standard engineering and machine design handbooks contain the formulas. When calculating torque capacities for grooved shafts by means of these formulas, the effective diameter must be considered to be the diameter at the bottom of the groove, and some additional allowance must be estimated for the stress concentration effect of the groove itself. For very accurate calculations in the case of grooved shafts, each specific geometry must be modeled and calculated by means of finite element analysis.

The choice of stainless steel alloy also affects the torque capacity. Ferrofluidic® grooved-shaft catalog products use a martensitic stainless steel alloy (416). Rigaku catalog products use a precipitation-hardening stainless steel alloy (17-4PH). Precipitation-hardening stainless steels generally exhibit higher strength (yield point and ultimate tensile strength) than do the martensitic stainless steels.

The profoundly negative impact of grooves on torque capacity is shown in this graph. The torque required to stress 416 stainless shaft material to its yield point has been calculated for grooved and ungrooved shafts of several diameters. The ratio of grooved to ungrooved torque capacity is also plotted ("Strength Reduction Ratio"). As expected, the impact of the grooves is proportionally more severe for smaller shafts. These curves should not be taken as product specifications, because no Safety Factor has been applied in the calculations.



### Improved Torque Specifications are Possible

When setting published torque specifications, manufacturers apply a Safety Factor to the calculated values. The magnitude of this factor may vary from one manufacturer to another, and may even vary from time to time for a given manufacturer. A review of published specifications in light of recent calculations and preliminary testing indicates that Rigaku/USA's published specifications have been excessively conservative. A program of testing and review is now underway to establish more accurate specifications in the future. Results to date indicate that the values should be approximately as shown in the following table. The revised Rigaku/USA specifications are for the standard shaft materials presently in use. It is possible to substantially increase these values if other shaft materials are used.

	Safety Factor	Torque Rating (lb-in)			
		0.250" shaft	0.375" shaft	0.500" shaft	0.750" shaft
Competitive Product Specifications	2.5 (estimated)	15	67	180	670
Current Rigaku/USA Specifications	>> 2.5	16	60	130	450
Revised Rigaku/USA Specifications	2.5	50	160	380	1400

### A Word of Caution About Bearings

In high-torque applications, it is possible to damage bearings while not overstressing the shaft, especially if the shaft is driven by pulleys or gears. If the driven load becomes jammed, feedthrough rotation will stop and the input end of the shaft will experience a side load which will be felt as a radial load by the bearings within the feedthrough. Under conditions of high torque and typical pulley and gear diameters, it is easily possible to exceed the static radial load rating of the bearings. If the drive system is connected to the input end of the shaft by a properly supported in-line coupler, side loading will not occur under these conditions, and the bearings will not experience significant radial loading. Even with freely rotating loads, this effect will be momentarily present at startup (due to inertia) if the drive system is capable of providing very high initial torque.

If load jamming is possible, users must also consider whether the jammed condition will result in side loading of the shaft on the output end.