euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Non-contact fluid rotary union design for heat load chopper spindles

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Abstract
Professional Instruments Company has worked on two different projects developing air bearing spindle assemblies for use in X-ray applications. Both projects had a requirement for cooling fluid to be delivered to a rotating disk without adding undue speed variation ("jitter") or rotational errors to the spindle. These projects led to the design of a unique non-contact fluid rotary union. This poster outlines the design of the rotary union and the two projects that required its use.

Fluid rotary union, Water-cooled, Non-contact

1. Introduction

Fluid rotary unions deliver fluid to a spindle rotor for either rotor cooling or coolant for a machining or grinding process. Conventional rotary unions rely on sliding seals that can add friction and unacceptable rotational errors to high precision applications. Professional Instruments developed a bespoke air bearing fluid rotary union (Fig. 1) out of necessity in the 1980s while working on a project for a high powered X-ray anode. The following section describes the design of the rotary union.

2. Non-contact fluid rotary union design

The design of the rotary union is a rotating shaft in a non-rotating housing supported by non-contact air bearings. A diagram of the design is shown in Figure 2.

Water is supplied to the union housing by two inlet ports 180° apart to balance forces. This water flows to a housing annulus, which feeds into porting to an o-ring sealed center tube of the rotating shaft assembly. From there it travels to the rotating disk. Heated water returns to a second housing annulus from a passageway around the outside of the o-ring sealed center tube. This water returns to the system chiller by two outlet ports that are also 180° apart. The union housing is supported by non-contact air bearings that are located on both ends. The symmetry of the design balances forces and simplifies high speed balancing of the system.

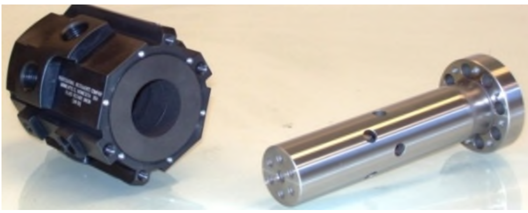

Figure 1. Non-contact fluid rotary union and shaft.

Tight clearance (15 µm) capillary seals provide resistance to flow to minimize leakage. Whatever fluid does leak past the outer capillarys returns to the chiller by a sump return line. Even tighter clearance air bearings (about 7 µm) are on either side of the sump return annuli. Pressurized air from the

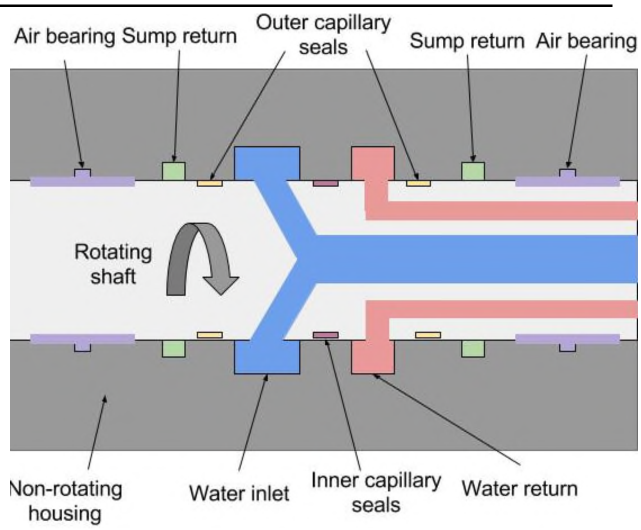

Figure 2. Features of the non-contact fluid rotary union.

bearings prevents leakage of the fluid past the sump annuli and into the bearing air gaps. Note that the sump effulent will contain both water and bearing exhaust air. A groove compensated carbon sleeve is used in the union housing to reduce friction and limit damage in case of an overload. Rotor plates on either end of the housing provide high clearance scavange fed thrust air bearings as axial constraints.

It is critical that the air bearings are supplied with pressurized air until the entire system is drained and dried out to prevent damage to the union.

3. Applications

The fluid rotary system design described in this poster has been used in a number of different precision spindle assemblies. Two projects are of particular note to the history of the non-contact fluid rotary union are the Perkin-Elmer X-ray anode and the synchrotron heat load chopper spindle.

3.1 Perkin-Elmer X-ray anode

Professional Instruments built its first non-contact fluid rotary union in the early 1980s when working with Perkin-Elmer on a spindle their XLS-1000 X-ray step-and-repeat lithography system [1]. The anode used a tungsten disk as the target that rotated at 8 000 RPM in vacuum of ~7×10^{-6} Pa (~5×10^{-8} Torr) with a ferrofluidic seal [2].

X-rays in the system were generated by focusing a 10 KeV electron beam on a 1.5 mm diameter spot on a tungsten plate. The tungsten disk needed to rotate smoothly and be cooled without introducing speed or rotational errors to the spindle. This led to the first design of the fluid rotary union sealed by non-contact air bearings.

While the design of the union was similar to other work done in the past, the cooling fluid introduced many challenges into the precision spindle assembly. In particular, balancing the assembly was difficult due to noise introduced by the flow of cooling fluid and the fluid pumps as well as thermal imbalances at the tungsten disk from asymmetrical fluid channels.

After design and process improvements (Fig 3.) the X-ray anode assembly was successfully used in the Perkin-Elmer Step and Repeat Lithography system[1].

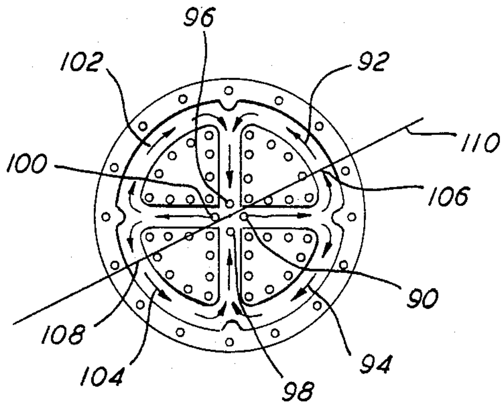

Figure 3. Cross-section of the final design for the cooling channels in the rotating disk.

3.2 Synchrotron heat load chopper spindle

In 2007, Professional Instruments was asked to design a heat load chopper spindle for use in the Argonne National Laboratory's synchrotron [3]. The design goal was to control the duty cycle of the X-ray beams to reduce the overall power to a level that would prevent damage to the more sensitive instruments downstream. The chopper spindle needed to block a 1.5 mm diameter, 520 W X-ray beam, while rotating with low error motion and minimal speed variation. The chopper disk was cooled via the non-contact fluid rotary union because of prior experience with the Perkin-Elmer project.

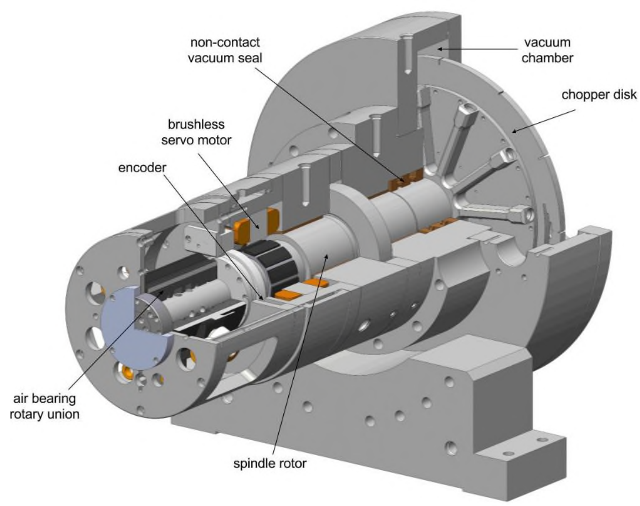

Figure 4. Features of the synchrotron heat load chopper spindle.

Similar to the Perkin-Elmer X-ray anode, the chopper disk needed to be cooled while rotating in a vacuum. However, instead of a ferrofluidic seal, this spindle utilizes differentially pumped annular non-contact vacuum seals to minimize jitter in the system. These seals also have minimal friction and no wear compared to ferrofluidic seals. Additionally, the cooling channels in the rotating disk were changed to curved channels for more symmetrical cooling and better flow.

The spindle delivered to the Argonne National Laboratory achieved vacuum levels of 7×10^{-4} Pa (5×10^{-6} Torr) and jitter measurements of 2 parts per million speed stability or σ of less than 25 ns over the range of operating speed for the spindle (4 000 RPM – 6 000 RPM). While in use, the spindle is able to reduce the power of the 520 W beam down to 1 W which is sufficient to protect the delicate instruments downstream in the process.

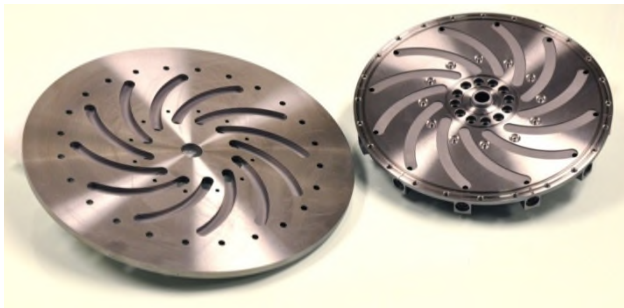

Figure 5. Fluid channels in the rotating disk of the chopper spindle.

4. Conclusion

Design of a novel non-contact fluid rotary union is described. The design enables cooling of a disk that blocks powerful X-ray beams during operation. The non-contact seals used in the design are vital for minimal speed jitter and error motion.

The non-contact fluid rotary union has been a critical component in a number of spindle assemblies over the years for Professional Instruments and will continue to be used into the future.

References

[1] LaFiandra, Carlo, and Gregory P. Hughes. X-ray Anode Assembly. The Perkin-Elmer Corporation, assignee. Patent US 4584699 A. 22 Apr. 1986.

[2] Suurmeijer B, Mulder T, and Verhoeven J, 2000, *Vacuum Science and Technology*, Jimenez S, Eindhoven, The Netherlands, pg 595-97.

[3] Byron Knapp, Dan Oss, Dave Arneson, Tim Graber, and Robert Henning 2016 Water-Cooled Heat Load Chopper For High-Energy Synchrotron Experiments, ASPE 31st annual Meeting.