

## Development of an Inflow Bernoulli Bearing for Improved Axial Stability in Fast and Slow MAS with Drop-in Rotors for Automatic Sample Exchange

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The classic Andrews/Beams drive/bearing design and later designs, such as those by Bartuska, Lewis, and others, have utilized outward flow in a conical space at the bottom of the rotor that establishes an axial bearing and may also provide some or all of the needed drive torque for the sample spinner. However, such designs appear to have insufficient axial stability for many gradient MAS methods and some HR-MAS applications. Moreover, prior MAS spinner designs do not appear to be compatible with the needs of CryoMAS™, where a zirconia dewar is required between the sample rotor and the cryogenic rf coils.

A novel inflow Bernoulli axial bearing for MAS has been developed

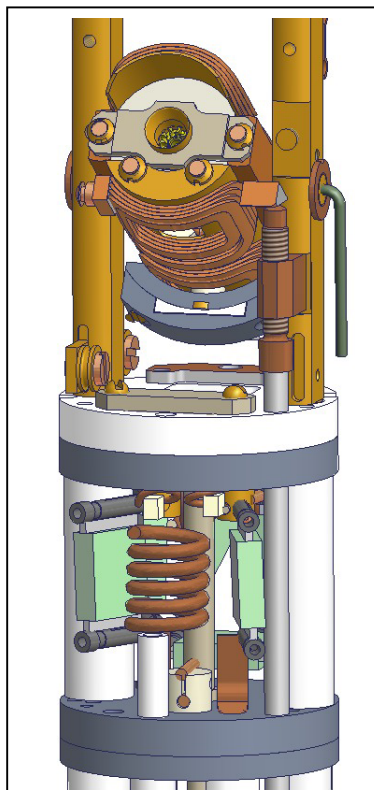


Figure 2. The novel DI-4 spinner is incorporated into the Doty OptiMAS™ probe, which utilizes cryogenic cooling of the critical components for maximum S/N in a triple-resonance NB MAS NMR probe.

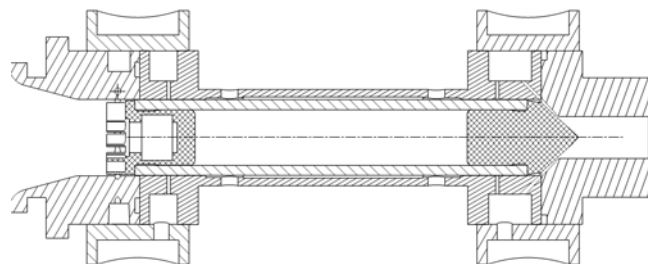


Figure 1. Spinner assembly for a "drop-in" rotor with a novel inflow Bernoulli bearing (shown on the right) demonstrated order-of-magnitude improvement in axial stability compared to previous designs compatible with automatic sample exchange and low-E cross-coils.

and will be described that provides exceptional axial stability as well as compatibility with CryoMAS™. Gas is injected radially inward with a large axial rearward component and a small negative azimuthal component into the conical bearing region from its periphery. A self-stabilizing axial bearing may be formed with improved stability and stiffness for rotor surface speeds up to at least 80% of the speed of sound. Typical axial oscillations, measured using a linear variable displacement transducer (LVDT), are under 2  $\mu\text{m}$  rms over a wide range of spinning conditions. ***This is an order of magnitude better axial stability than what has often been seen in some alternative spinner designs compatible with automatic sample exchange.***

Motive power to spin the rotor is provided by a radial-inflow microturbine at the upper end of the rotor in a way that is compatible with automatic sample exchange. A combination of CFD and FEA analysis was used in the turbine and bearing optimization.

The 3 mm spinner (**DI-3**) demonstrated 30 kHz MAS, and the **DI-4** (4 mm rotor) achieved 23 kHz, as well as  $\sim 1$  Hz spectral resolution on  $^1\text{H}$  with excellent lineshape. The spinner designs are compatible with extended VT ranges, automatic sample exchange, and ***ultra-low-E cross-coils for order-of-magnitude reduction in rf sample heating.*** Such cross-coils require extra external access and extra rotor length compared to single solenoids.

The DI-4 (4 mm Drop-In) sample spinner with the inflow Bernoulli bearing, similar to that shown in **Figure 1**, is incorporated into a triple-resonance, multinuclear MAS probe with a magic angle gradient (**MAG**) coil capable of 400 G/cm, automatic sample exchange capability, and extended VT range, for use in a narrow-bore 750 MHz magnet, as shown in **Figure 2**. Preliminary S/N, resolution, and gradient-MAS test results will be reported.

A specialized adaptation of the 3 mm spinner includes the zirconia dewar between the rotor and the rf coils to permit sample temperatures well above RT while the rf coils are at cryogenic temperatures. ***Preliminary test results on this 3 mm CryoMAS™ spinner will also be reported.***

### Reference:

F. D. Doty, Y. A. Yang, and G. E. Entzminger, "Magnetism in NMR Probe Design Part II: HR MAS," *Concepts in Magn. Reson.*, Vol 10(4), 239-260, 1998.