Comparison between Air and Ball Bearings for GGG.

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1 Ball Bearings

In ball bearings the balls are in constant contact with and form a solid bridge between the bearing races. Each race is a ring with a groove where the balls rest. The groove is usually shaped so the ball is a slightly loose fit in the groove. Thus, in principle, the ball contacts each race at a single point. However, a load on an infinitely small point would cause infinitely high contact pressure. In practice, the ball deforms (flattens) slightly where it contacts each race. The race also dents slightly where each ball presses on it. Thus, the contact between ball and race is of finite size and has finite pressure. Note also that the deformed ball and race do not roll entirely smoothly because different parts of the ball are moving at different speeds as it rolls. Thus, there are opposing forces and sliding motions at each ball–race contact. Overall, these cause bearing drag and noise.

Super precision grade ball bearings are manufactured with typical $\sim$ 100 nm geometric tolerances: balls are manufactured with $\sim$ 100 nm sphericity and $\sim$ 500 nm diameter tolerance. Very roughly, a 5 cm diameter ball bearing can then cause a shaft fitted to the inner race to tilt by some μrad. Due to the diameter tolerance, different balls in a bearing rotates at different rates, giving rise to a sistem with complex periodicities, also at low frequencies. The complexity of the ball bearing can then result in high and low frequency shaft tilt noise in the μrad region.

2 Air Bearings

Air bearings use a thin film of pressurized air to support a load, the same way the puck on an air hockey table "floats" on air. This type of bearing is called a "fluid film" bearing. Fluid film bearings have no solid-to-solid contact under typical running conditions; instead, a film of pressurized air forms a layer between the solid machine elements and serves to transfer forces from one to the other. The fluid is able to transfer forces because as the fluid is pushed through the bearing gap it generates a pressure profile across the bearing area. Fluid film bearings offer a number of advantages over mechanical bearings. First, because there is no contact, air bearings do not suffer from wear or heat generation due to friction. They also exhibit no starting or running friction, even under their highest design loading. In addition, the fluid film acts to center and average out small scale errors in the components resulting in motion which can be more accurate than the individual bearing components. Air bearings also offer much higher stiffness than rolling element bearings because the air film fully supports the components, as opposed to balls or rollers which have point or line contact and are therefore limited due to Hertzian contact stiffness.

Air bearings require very tight bearing gaps for proper operation ($10\,\mu$m) which translates into extremely high accuracy requirements on the components. Gas bearings have essentially zero friction at all speeds and because the tight bearing clearances demand high accuracy components this results in extremely high accuracy motion. Air bearings offer good noise performances because they have excellent accuracy, precision and repeatability. They offer high accuracy because the components are manufactured with extremely tight tolerances and because of the air film's averaging effects. Typical rotary runout can be as low as $10\,nm$/cm and tilt characteristics as low as $0.5\,\mu$rad/cm. Because the air bearing has two surfaces and only two surfaces, the tilt noise is essentially concentrated at the rotation frequency, while the noise performance is order of magnitude better at low frequency.