Air Bearing Spindle Crashproof Technology

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Abstract

The goal of this paper is to provide some background on air bearing spindle crashes, which are the failures that can result from accidental contact between the rotor and the stator, and to discuss some of the technology Seagull has developed to prevent those failures. Accidental rotor-stator contact, or rotor touchdown, can result in catastrophic bearing failure if not dealt with appropriately. Rotor touchdown is generally caused by loss of air film, exceeding the bearing capacity, bearing distortion due to mechanical or thermal influences, or contamination. Through a judicious selection of bearing materials and design practices, Seagull has practically eliminated bearing failure caused by rotor touchdown. Even after repeated cycles of turning on and off the air to a Seagull bearing spinning at high speed, the bearing returns to normal operation once air is restored. For more information on Seagull bearings and to watch a demonstration video of the Seagull crashproof technology, please visit the Seagull website at www.seagullsolutions.net.

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Air Bearings and Air Bearing Crashes

Rotors in air bearing spindles are completely supported by films of high-pressure air. Other types of bearings may have rolling elements, such as balls or cylinders, separating the rotor and the stator, or films of oil, like the bearings used in engine crankshafts. Since the rotors in air bearings only come in contact with air, they are almost completely frictionless. They have much greater rotational accuracy than ball and roller bearings and are much cleaner than oil film bearings, making them ideal for many applications. One traditional disadvantage to air bearings, however, is that they are subject to crashing. "Crashing" refers to failure due to accidental contact between the air bearing rotor and stator, which damages one, or both, of the active surfaces in the bearing.

Compensating air bearing spindles operate as mechanical feedback systems. In an "aerostatic, orifice compensated" design approach, compressed air flows through small holes in the air bearing stator, into the narrow gap between the bore of the bearing and the outside of the rotor, and from there travels along the length of the shaft until it escapes into the atmosphere. When loads are applied to the rotor, the pressure distribution in the air film reacts automatically to develop forces that resist deflection and displacement of the rotor axis. The combination of the air film and the bearing geometry acts as sensor, controller, and actuator in a feedback loop that works to limit deflections in the rotor axis. The system works very well, up until the point where the supporting strength of the air film is exceeded and physical contact occurs.

"Crashing" is an appropriate term for air bearing failure due to accidental rotor touchdown. When the spinning rotor comes in contact with the non-moving stator, frictional interaction can cause instantaneous thermal and shock damage to both parts. In extreme cases, the parts friction weld to each other causing very sudden catastrophic failure. When a crash leads to friction welding, all of the kinetic energy in the rotor and the payload, stored as angular momentum, suddenly gets converted to sound, heat, and shrapnel. The air bearing becomes a bomb that can injure both equipment and personnel. Even relatively minor crashes can release debris into the environment and destroy local cleanroom cleanliness levels. Crashed air bearings often must be completely rebuilt or replaced, requiring downtime for cleanup, repair, and reassembly, which costs time and money and potentially compromises work in progress.

Why Air Bearings Crash

Accidental air bearing rotor touchdowns can occur for any number of reasons, the most obvious being the loss of supply air pressure to the bearing. If the bearing cannot develop enough supporting air pressure internally due to aerodynamic effects, the rotor will end up impinging against the stator. Frequently pressure sensors and controller shutoff switches are used to cut power to the spindle if an air line breaks or gets kinked, but crashes occur so suddenly that such methods are not fast enough to avert disaster. Even when the external air supply pressure remains uninterrupted, other phenomena can occur inside the bearing to weaken the air film and cause the air bearing to fail. Half speed whirl is such a phenomenon, and the magnitude of its effects depends on the rotor speed and the bearing geometry.

Bearing overload is another common cause of accidental rotor touchdown. Every air bearing has a maximum load capacity, above which the air film can no longer support the rotor and the payload. When the bearing capacity is exceeded, the rotor comes in contact with the stator. Bearing loads can be applied to the rotor externally, such as from gravity acting on a massive payload or from a working surface pushing against a grinding or cutting wheel mounted on the rotor, or the bearing loads can come from centrifugal forces created by imbalances in the spinning rotor and payload. For a given amount of imbalance, the centrifugal force on the rotor grows geometrically with rotor angular velocity. When the rotor RPM doubles, the centrifugal force quadruples. Even small imbalances in the payload can cause very large forces and moments on the rotor at high RPM. If care is not taken to ensure that the forces on the rotor remain within the working capacity of the air bearing, then some rotor touchdown is inevitable.

Another cause of air bearing rotor touchdown is distortion of the bearing geometry. Most bearings are tolerant of changes in the working clearance of up to ~20% from the design optimum. When the working clearance changes more than 20%, measurable performance degradation occurs, such as reduced capacity, reduced stiffness, compromised runout, modified windage, instability, and possible rotor touchdown. Changes in the bearing clearance can be caused by thermal growth, centrifugal expansion, and distortions from warped parts or improper setups. Some bearing geometries are more susceptible to these failure modes than others.

The final common cause of rotor touchdown and seizure is contamination buildup in the bearing clearance from the air supply. While bearings are designed to consume as little air as possible, the amount of air supplied over time can add up to a large volume. Even small amounts of contamination will tend to build up in the very tight working clearances within an air bearing. Air enters the bearing at a high pressure and leaves at a lower pressure. Often there is a significant pressure drop designed in at a restrictor orifice or other flow-regulating feature. This sudden pressure drop causes condensation to occur, often gathering on a particle or other bit of debris. If the buildup becomes too large, then the rotor can become effectively “glued” to the stator. The rotor may not actually come in direct contact with the stator, but the end result is the same.

How To Prevent Air Bearing Crashes

The first step to preventing an air bearing crash is to ensure that the rotor does not come in contact with the stator. To prevent rotor touchdowns, the air supply must remain constant and clean, the forces on the rotor must remain within the working capacity of the bearing, and the bearing distortion and operating conditions must remain within the acceptable limits. Even when facilities do a great job of maintaining proper air bearing working conditions, though, accidents can and do occur. Automation can run into spinning payloads and air lines and compressed air systems can fail. Rotor contact with the stator is almost inevitable at some point in an air bearing's life span. The best way to prevent rotor crashes is to design the air bearing in such a way that rotor touchdown does not cause bearing failure.

Air bearings fail when the rotors come in contact with the stators because of the mechanical and chemical interactions between the two parts. Seagull has developed a tribological system that is very forgiving to such events by choosing construction materials that have a natural resistance to friction welding to one another. When the rotors in Seagull air bearings come in contact with the stators, they do not fuse (alloy), fracture, gall, shatter or pulverize under the extreme conditions created by the high-speed rotor touchdown situation, as other bearings do. Because of the total lack of tribological interaction between the materials, the touchdown event is spread out over a sufficiently long time such that no real or permanent damage will result. Seagull air bearings can immediately return to full functionality as soon as air pressure is returned, even after multiple touchdown events have occurred. The bearing has been "crashed" and no damage results!

Conclusion

Seagull air bearing spindles offer the most crashproof design of any bearing on the market today. Unlike any other bearing, the materials used in Seagull air bearing rotors and stators practically eliminate traditional failure caused by rotor-stator contact. Part coatings wear away over time and merely delay the problem. Air supply safety mechanisms only partially solve the problem and cannot prevent catastrophic accidents. Rotor touchdowns are almost impossible to prevent over the life of the bearing, making crashes inevitable in bearings that cannot tolerate repeated rotor-stator contact.

In addition to being able to tolerate repeated rotor-stator contact, the unique biconic geometry of Seagull's latest air bearing makes accidental rotor touchdown far less likely than for other bearings. The basic shape of the biconic components guarantees that the aspect ratio of the parts is maintained even when the stator is one temperature and the rotor is another. For this reason high speeds and/or adverse operating conditions do not exceed the 20% distortion rule. An additional benefit of the biconic geometry is that the working surfaces are normal to the tilting motion that results from an axis shift. This makes the working air film more efficient in resisting deflections and as an additional benefit minimizes the amount of working surface needed to support a given load. This then results in reduced windage and therefore less induced heating due to aerodynamic friction. The benefit is higher stiffness at all speeds combined with an extended speed range. Half speed whirl nodes are also blended into submission because of the constantly changing radius of the working surface. While the phenomenon still exists, it occurs only in a percentage of the bearing where the balance of the working surface can be relied upon to carry the required load. This is an important characteristic, necessary to reach higher speed ranges.

Seagull Spindles are manufactured from materials that are fully corrosion resistant under the conditions anticipated in all known applications. For Seagull "in-house" part processing, bearings are in continuous use in wet grinding applications with no detrimental effects. All that is needed is a continuous supply of clean/dry air. Even after repeated cycles of turning on and off the air to a Seagull bearing spinning at high speed, the bearing returns to normal operation once air is restored. Even with a severely imbalanced payload, at 10,000 RPM a Seagull bearing runs almost as well without air as it does under normal operating conditions. When air is removed from an imbalanced Seagull Hi-Capacity bearing running at speeds in excess of 20,000 RPM, the running speed lowers and the current through the motor increases, but the bearing returns to normal operation when air is restored as if no fault condition had ever occurred. For more information on Seagull air bearings and to watch a video demonstration of the Seagull crashproof technology, please visit the Seagull website: www.seagullsolutions.net.