Advanced bearing systems for large diameter rotors

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Abstract

This paper deals with two (industrial) design cases of high accuracy rotor bearings. The first is of the Philips Brilliance iCT (intelligent Computer Tomography) diagnostic imaging system. The second of an E-beam wafer lithography system being researched and developed by KLA-Tencor. Both bearings carry rotors greater than 1 m diameter. The maximum rotational speeds are in the order of 300 revs/min. Though at first glance comparable, the differences in requirements and application have resulted in totally different bearing solutions. The CT rotor-axis lies horizontally; the rotor accommodates X-ray source, detector, collimator and generator and has a large inner bore for patient access. The total weight amounts to more than 1000 kg! Because of the large weight, required accuracy and high circumferential speed (up to 30 m/s) the CT rotor is equipped with air bearings. The E-beam system has a vertical rotor-axis. The rotor carries the wafers in a horizontal plane. The rotor (mass = 100 kg, diameter = 1 m) needs to be operated in vacuum. The E-beam bearing system is based on active magnets. Both rotor systems have been realized and tested.

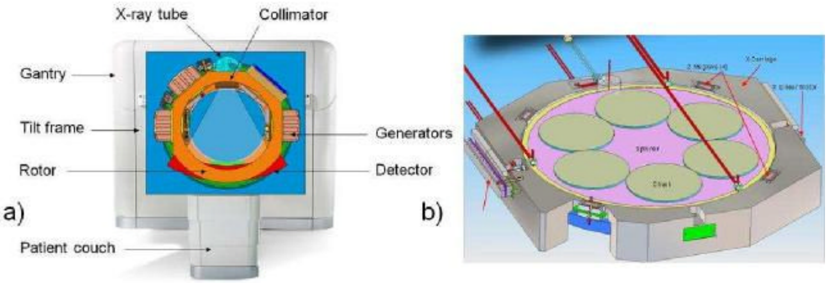

Figure 1: a) Overview CT rotor, b) rotor with 6 wafers placed on 320 mm center Radius

1 Bearing principles

Demands applying to bearing systems concern load capacity, lifetime, stiffness, running accuracy, reliability and so on. In case of the E-beam rotor the list is extended with requirements regarding vacuum compatibility, magnetic stray fields, controllability and several others.

1.1 Air bearings

The large diameter makes it impossible to have the standard concept of cylindrical air bearings. Instead air bearing pads are used. The principal design challenges are the high circumferential velocity, bearing surface accuracy, swivel function and the manufacture and mounting of the large diameter (1680 mm) race. The high circumferential velocity causes significant drag and impacts the pad pressure distribution to such an extent that in case of orifice bearings at one side of the pad the load capacity and stiffness plummets. This being the reason porous air bearings have been selected. Simulations of pressure distributions (Figure 2) show the porous bearing having a more advantageous behaviour, however the pressure point shifts towards the bearing pad output side.

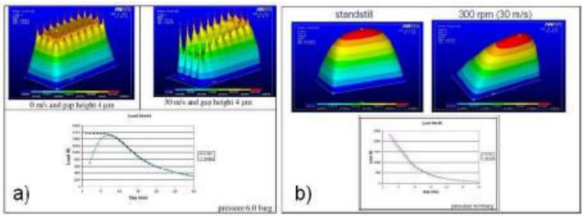

Figure 2: a) Load capacity of an orifice air bearing at stand still and 30 m/s speed, b) Load capacity of a porous air bearing at the same speeds

The conclusion from the simulations was that porous (carbon) air bearings were preferred and the total bearing surface tolerances (pad and corresponding rotor area) had to be within 2 µm. The shift in pressure point lead to the design of a pad with eccentric swivel axis.

1.2 Active magnet bearings

Active magnets (see Figure 3) are electro magnets generating (reluctance) forces. In contrast to Lorentz actuators, reluctance actuators have a non-linear relation between current and (attraction) force, see Figure 3.

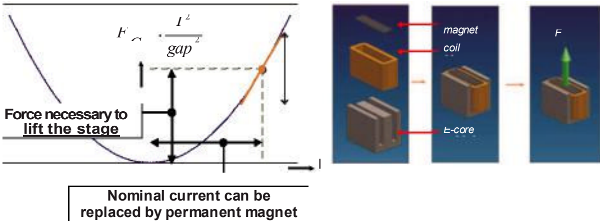

Figure 3: Hybrid active magnets comprise of an E-core, coil and permanent magnet

To achieve pretension or to compensate for gravity forces of the levitated rotor and to linearize the current force relation a permanent magnet is placed inside the "E-core". In this way a frictionless and contactless active bearing is created that operates with almost zero dissipation (less than 100 [mA] at nominal position). The rotary stage consists of 9 actuators which generate the generalized forces to control the 6 degrees of freedom of the rotary stage. Eight of those actuators are hybrid electromagnets, a reluctance actuator (E-core shape) with a permanent magnet. The 9th actuator is the moving coil rotary motor.

2 Design of bearing systems

The CT rotor bearing has two pads carrying the weight and taking care of the rotor's radial position. Three pads constrain the remaining axial degrees of freedom. Two axial pads are spring preloaded with opposing pads. Since the surfaces of the axial bearings are offset with respect to the centre of gravity, preloading the other is taken care of by gravity.

The bearing race has a T-shaped cross section. Is has to garantee shape accuracy, but at the same time it is part of the rotor construction suspending the imaging components. To prevent unroundness induced by the active parts, the race is "uncoupled" from the remaining rotor part by means of a "nest-of-springs" construction.

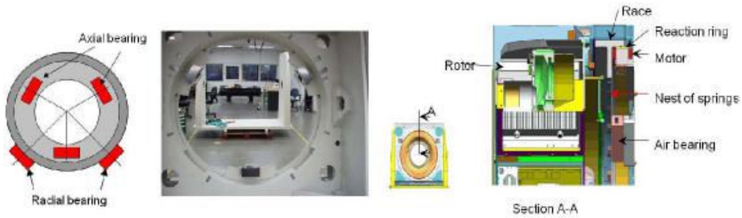

Figure 3: CT air bearing configuration and nest-of-springs suspension

Active magnet bearings operate under servo control. The position of the rotor with respect to the base is measured using multiple encoders and inductive probes. Sensor and actuator redundancy is used to differentiate between and compensate for reproducible error motion and sensor or actuator artifacts. This involves systematic and novel (in situ and real-time recursive) calibration and control schemes. One of the main requirements of the stage besides being vacuum compatible and being magnetically stray field compliant and robust under operation, is the limited allowable radial (servo) error motion (for low frequencies, less than about 1 μm and especially for frequencies above 100 Hz, less than 1 nm).

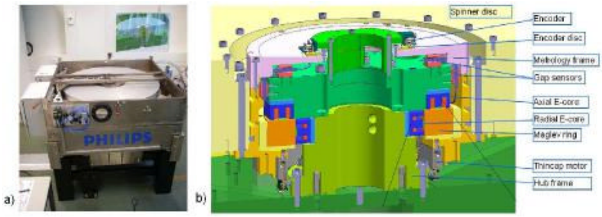

Figure 4: a) Overview b) The bearing hub containing 8 E-cores, 12 Eddy current sensors and 2 rotary encoder heads

Both rotor systems have been built and tested and perform conform specification. Special attention is paid to safety.

References:

[1] U, Ummethala, G. Angelis, A. Van Lievenoogen, "Progress on High Precision Maglev Stage Technology for Parallel High-Throughput Reflective Electron Beam Direct Write Lithography", ASPE 2011 Denver