AIR BEARINGS IN HIGH PRECISION SYSTEMS

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Abstract:

In high precision system applications low friction levels between components are desirable. Moving heavy parts at high speeds and accelerations without friction is possible by using air bearings. The main failure of the air bearings is the wear phenomenon (modification of surface topography) that occurs due to crash into the counterpart when air supply is interrupted. The aim of this research is to investigate different types of air bearings for a large number of crashes using real operational parameters from the field: speed, acceleration, load and supply air pressure. The real crash phenomenon in a high precision machine has been replicated using a test setup. During testing, evolution of air bearing surface topography and air bearing characteristics (gap and flow) after different number of crashes are investigated. Test results show that some air bearings are not reaching the specified number of crashes due to large defects that occur on the bearing surface. Some specific relations were found between crash defects and parameters such as the air gap size and the direct contact between opposing surfaces. The preferred type of air bearings shows good performance even above the maximum specified number of crashes. This behavior can be explained by low friction level during crash tests between the opposing surfaces. The test results from this investigation produced a reliable candidate for air bearings in the high precision system application.

Keywords: air bearings; crash; surface topography; wear; failure

1 INTRODUCTION

Last decades brought high accuracy demands in production equipment applications. Moving heavy parts with high speeds and acceleration is possible using air bearing interfaces. This type of bearings provide low friction levels due to formation of a thin film of pressurized air (gap) between air bearing pad and bearing track beam surface. At normal operation, surfaces are separated (non-contact) and avoid traditional bearing problems of friction and wear [1]. During lifetime, operational conditions can be changed due to malfunctions. If air supply source is interrupted temporary during bearing motion or if air bearing is overloaded serious bearing damage can result (modification of bearing surface topography). The severity of these damages lead to complete shutdown of equipment in the field causing production losses and maintenance costs. The aim of this research is to find a reliable candidate for air bearings that can operate even after a large number of crashes, resulting an improvement of lifetime and performance of the high precision system application.

2 MATERIALS

As was shown by Franklin et all [2], choosing the right material combinations in air bearing/beam interference may improve lifetime of professional equipment. To find appropriate materials for application, wear tests are performed in laboratory on a variety of materials using a pin-on-disk tribometer (the pin represents the air bearing pad and the disk represents the beam material). All tests are made under the same conditions presented in Table 1. The main criteria in material selection were: the amount of pin wear and the damage to the disk. Based on test results (see Table 2), the following materials were selected for air bearing/beam interface: AISI 300 series (Type 1)+Kolsterising / AISI 400 series+hard chrome layer, AISI 300 series (Type 2)+Kolsterising / AISI 400 series+hard chrome layer (see material properties in Table 3).

For air bearings pad has decided to use carbon porous media (graphite) as a third option due to following benefits: is very crash resistant [1], eliminates damage to the guide surface and lower air consumption (control a uniform airflow across the bearing surface trough a large number of holes in the porous material). Challenges and controlling of the manufacturing process of porous media air bearings is described in [3].

Table 1. Test conditions used in wear tests

Parameters	Value
Load	5 N
Sliding velocity	0.5 m/s
Test duration	60 min
Pin geometry (bearing feet)	radius 30 mm and 0.2 µm roughness
Disk geometry (beam)	flat and 0.4 µm roughness

Table 2. Results of wear tests

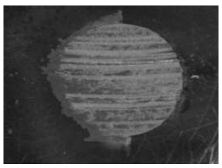
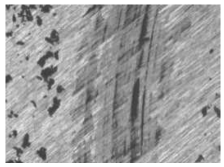
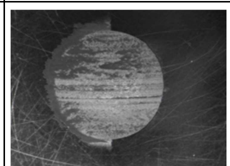
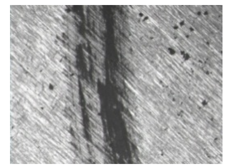
AISI 300 series (Type 1)+Kolsterising (pin) AISI 400 series+hard chrome layer (disk)	AISI 300 series (Type 2)+Kolsterising (pin) AISI 400 series+hard chrome layer (disk)
 	 
Wear scar diameter d = 3.4 mm Wear rate k = $2.7\cdot10^{-14}$ m^2/N	Wear scar diameter d = 3.1 mm Wear rate k = $2.1\cdot10^{-14}$ m^2/N

Table 3. Selected materials and surface treatments properties

Materials	Description
AISI 300 series + Kolsterising	**AISI 300 series** – austenitic stainless steel **Kolsterising** is a thermo-chemical carbon diffusion process.
Porous carbon media	**graphite**
AISI 400 series + hard chrome layer	**AISI 400 series** – corrosion resisting steel Hard Chrome plating is applied to ferrous and nonferrous materials to improve wear and abrasion resistance, reduce friction, prevent seizing and galling.

Three types of air bearings are selected for testing. The main characteristics are shown in Table 4.

Table 4. Characteristics of the air bearings

Type	Operational pressure [bar]	Load [N]	Dimensions [mm]	Average surface pressure [MPa]	Materials	Air flow - orifice geometry
1	5.5	2000	48 x 143	0.29	AISI 300 series + Kolsterising	slots
2	5.5	1800	57 x 127	0.25	AISI 300 series + Kolsterising	holes
3	4.1	1100	50 x 100	0.22	Porous carbon media	-

All three type of air bearings result in an average surface pressure between 0.22 to 0.29 MPa.

Flatness of the beam plays a very important role in precision of the air bearings. Therefore measurements were done in 3 different places over a 120 mm length on beam surface. The results indicate a flatness less than 3 µm. Applying a much harder coating layer on bearing track beam improves the resistance to damages during crashes and lowers the maintenance time in the field (maintenance time to replace the air bearings is less compare to change the bearing track beam).

3 CRASH SIMULATION TESTS

3.1 Air bearing crash test set-up

The main failure of the air bearings is the wear phenomenon that may occur during the crashes into the bearing track beam when air supply is interrupted. The real crash phenomenon in a high precision machine is replicated in a test setup (see Figure 1) in which real operational parameters from the field are used: speed, acceleration, load and supply air pressure.

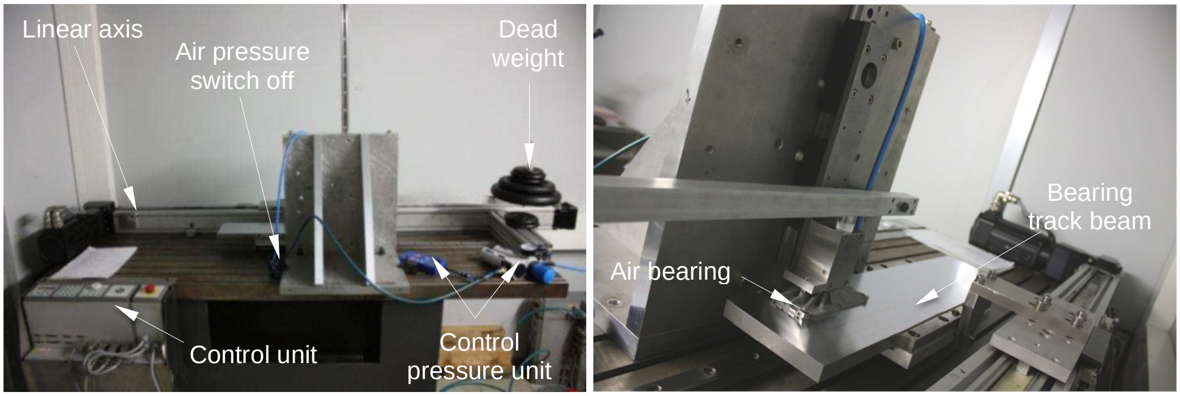


Figure 1. Crash test setup

During testing the air bearing is fixed and the beam is attached to a linear axis that controls the speed and acceleration by a control unit. The operational air pressure of the air bearings is adjusted from 10 bars to the nominal values (see Table 4) through a control pressure unit that consists of a pressure regulator, a filter and a pressure meter. The air bearings are loaded by a counter lever system using dead weights that correspond to real load values from the field.

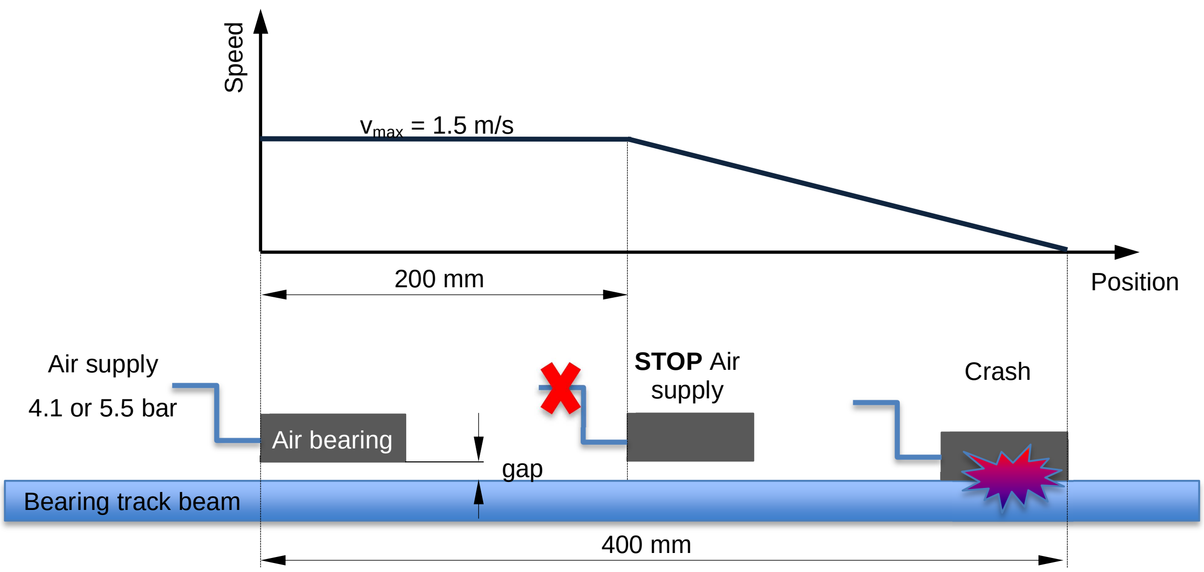


Figure 2. Steps in simulation of air bearing crash test.

Figure 2 shows the simulation of an air bearing crash. The first step consists in opening the air supply and adjusting it to operational pressure of the air bearing. At this moment the air bearing and the track are separated by a few micrometers air gap. Once the bearing is operational we continue to apply dead weights until the bearing is loaded properly.

The bearing track is set to move on a 400 mm distance at normal operation speed (1.5 m/s) and acceleration (20 m/s^2). At the half of this distance the air supply on air bearing is interrupted at full speed by a switch unit causing the bearing feet to crash in the bearing track. To repeat again the crash phenomenon, the air supply will be open so that when the beam is moving back to the initial position, no defects may occur to bearing feet or beam surfaces. By applying the above mentioned steps, the crash occurs always in the same place on the bearing track surface.

3.2 Testing parameters

Before starting the proposed tests all air bearings are controlled on the specified characteristics: flow and gap. Each type of air bearing is tested two times using tests parameters presented in table 5.

Table 5. Test parameters used in crash simulation tests

Test parameters	Values
Load	1100 – 2000 [N]
Air pressure	4.1 and 5.5 [bar]
Crash speed	1.5 [m/s]
Acceleration	20 [m/s^2]
Temperature	22 ± 5 [^0C]
Number of crashes	1 to max. possible

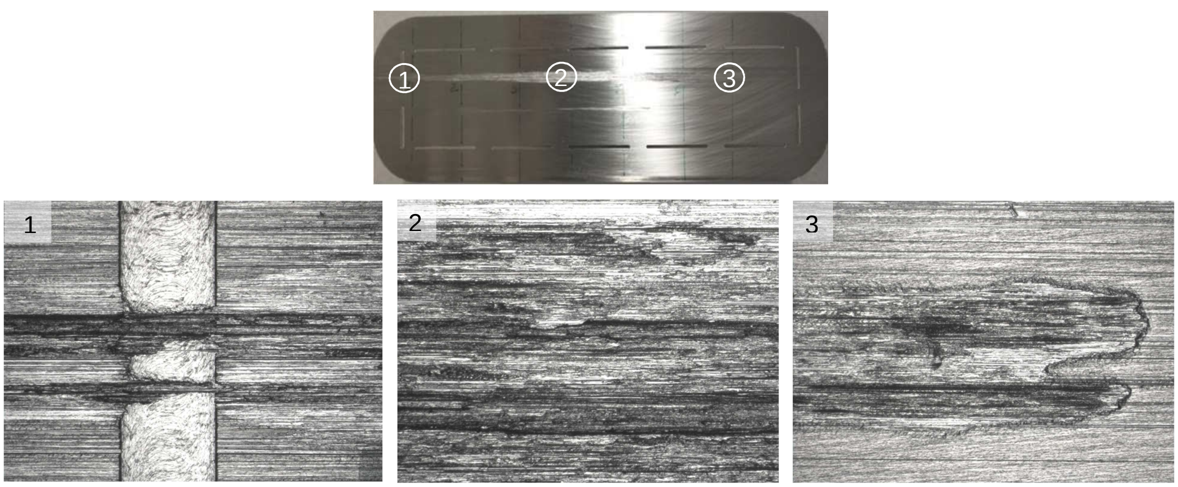
3.3 Results

The results from the crash simulation tests show the behavior of the air bearings as in real application. Their performance is measured by the number of crashes that the system could still operate under normal operational conditions.

3.3.1 Type 1

At type 1 air bearings, defects are observed on bearing surface after first crash. Tests are continued and after 8 crashes the system fails. Roughness measurements performed in 7 different places on bearing surface indicate a height of defects between 20 to 25 µm. These values are much larger compare to initial measured air gap size and lead to direct contact between surfaces. Figure 3 shows defects after crash simulation in different regions on air bearing and beam surface. On beam surface due to high impact collision during crashes, cracks are observed and in some regions the hard chrome layer is flake off.

a) defects on air bearing surface on three different positions: 1, 2 and 3



b) defects on bearing track (beam)

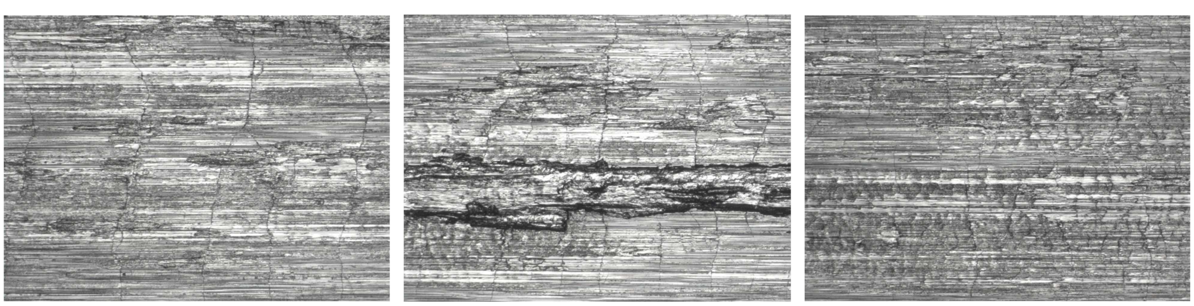
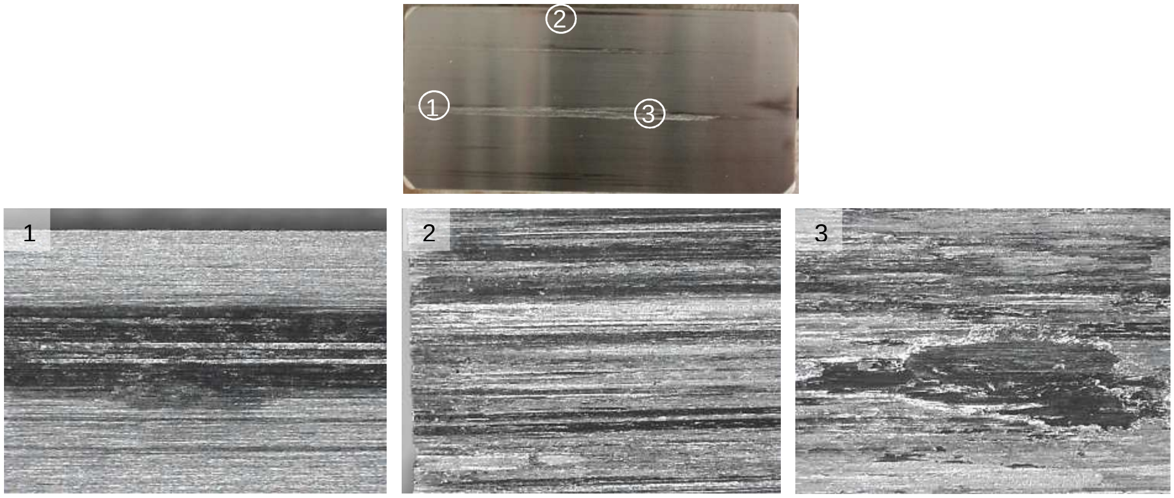


Figure 3. Defects after 8 crash simulations on air bearing (Type 1) and beam surface

3.3.2 Type 2

The maximum number of crash simulations reached for the type 2 air bearing is 16. The height of defects measured on air bearing surface is between 18 to 35 µm, much larger compare to operational gap dimension. After system failure, defects are observed along the beam surface: cracks into chrome layer and seizure traces due to adhesive wear phenomenon that occurs during high impact (see Figure 4, b).

a) defects on air bearing surface on three different positions: 1, 2 and 3



b) defects on bearing track (beam)

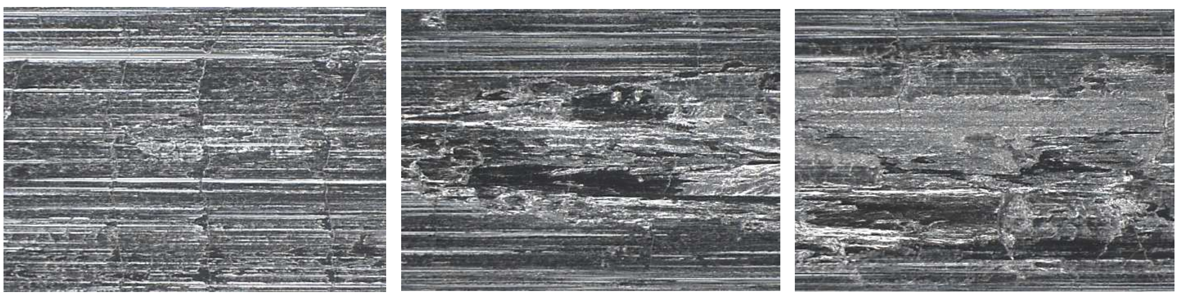
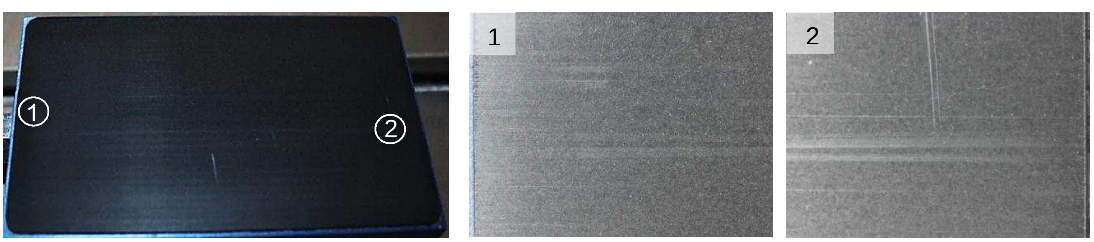


Figure 4. Defects after 16 crash simulations on air bearing (Type 2) and beam surface

3.3.3 Type 3

Type 3 air bearings have reached a total of 50 crashes and the air bearing/beam interface was still operational being able to continue crash simulations.

a) defects on air bearing surface on two different positions: 1 and 2



b) Defects on bearing track beam

Figure 5. Defects after 50 crash simulations on air bearing (Type 3) and beam surface

As is shown in Figure 5, both surfaces present no major defects. Roughness measurements on air bearing surface indicate defect heights of 0.2 to 0.8 µm. During impact, particles from air bearing feet material are generated and form a thin layer on beam surface that could behave as a solid lubricant improving the wear of surfaces (porous media material has low hardness compare to hard chrome layer).

4 CONCLUSIONS

The main goal of this investigation was to find a suitable candidate for air bearings in a high precision system application using real operation conditions as test parameters. Three different types of air bearing pads materials are selected. An average surface pressure between 0.22 to 0.29 MPa can be reached in air bearing interface (this values are calculated based on load and air bearing dimensions).

Test results presented in Table 6, shows that two types of air bearings fail after 8 respectively 16 crashes, due to damages that occur on air bearing pad and bearing track surfaces. This number of crashes is lower compare to the specified lifetime.

Table 6. Results of crash test

Type	Number of crashes	Average surface pressure [MPa]	State	Height of defects [µm]
1	8	0.29	failure	20 - 25
2	16	0.25	failure	18 - 35
3	50	0.22	still operational	0.2 – 0.8

Surface defects are observed after first crash simulation and are increasing with number of crashes. In time their size becomes larger than the operational air gap that separates the bearing feet and the beam. At this point, contact between the mentioned surfaces cannot be avoided. Continuing crash simulations, high friction is developed at microscopic level of asperities and leads to occurrence of adhesive wear phenomenon (welding of surfaces) and after several crashes failure of the air bearing (seizure).

Damages on beam surface have been identified as cracks into hard chromium layer. Due to large impact forces, hard particles from beam coating layer are removed and may interfere between the two separated surfaces causing damages on air bearing surface.

In case of type 3 air bearing, the size of the identified defects on bearing surface is below 0.8 µm height and damages on air bearing guide surface are not visible. This can be a result of low friction properties of porous carbon media material that increases the life of the air bearings. Conducted tests have shown good performance even above the maximum specified number of 50 crashes. Based on these results, the type 3 air bearing is considered a reliable candidate for high precision system application.

5 REFERENCES

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