A Discussion on Stability of Air Bearing Spindles

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Stability is a very common but difficult to solve problem in an air bearing system. The most cases that instability occurred were due to the lower damping in air bearings. It has been experimentally and theoretically verified that the stability of an air bearing will be increased by applying an increased external pressurized air into bearings [1], [2]. However, in our studies, instability appeared at lower speed with higher external supply pressure, and the speed at which instability appeared was increased with a decrease of external supply pressure. This phenomenon is contrary to normal analysis on stability issue. This paper will discuss this issue.

1. Introduction

Air bearings possess lower damping than other fluid lubricated bearings. Because of this characteristic, the high speed stability becomes a very important topic in the design of air bearings.

Firstly, our design goal was to develop a spindle that was able to handle twelve (12) computer disks and run 20,000 r.p.m. with eccentricity rate < 0.65 at 90 psi supply pressure. Even though the spindles can be balanced up to grade g0.5, because of test procedure operated by customers, the reality of imbalance after randomly adding the twelve disks on clamp was much worse than grade g0.5, which caused a large centrifugal force at 20,000 r.p.m. It is obvious that, the most focus should be on how to increase the bearing stiffness and load capacity on a dimension-limited air bearing to achieve the eccentricity ratio of less than 0.5.

Because of the dimensional limitation, even though the supply pressure was 90 psi, the static stiffness was still low, relatively. One important factor that can be used to increase the load capacity and stiffness was the aerodynamic property. In our regular Total Indicator Runout (TIR) tests, the TIR started to increase much more rapidly once the speed was over 15,000 rpm. Therefore, we needed to design an air bearing in which the aerodynamic performance should gradually play more important role on stiffness and load capacity at speed over 15,000 rpm. Based on this consideration, an air bearing spindle was designed with high pressure ratio and tighter air gap to provide higher dynamic performance. However, with heavier clamp made of steel instead of the one made of aluminum, the air bearing spindle exhibited a speed stability problem. The speed at which instability appeared decreased with the increase of supply pressure. This phenomenon led us to investigate the reasons.

2. Experiments and Analysis

Two types of clamps were used - aluminum clamp and steel clamp. The test setup was showed on Fig. 1.

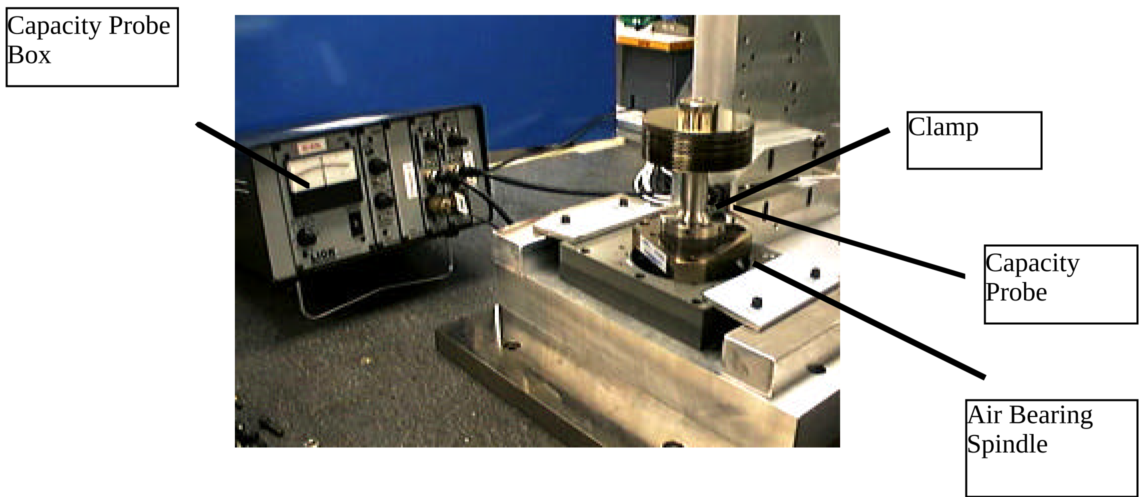

Fig. 1 Setup of Tests

2.1 Tests with light clamp made of aluminum

TIR test results of air bearing spindles showed on Fig. 2.

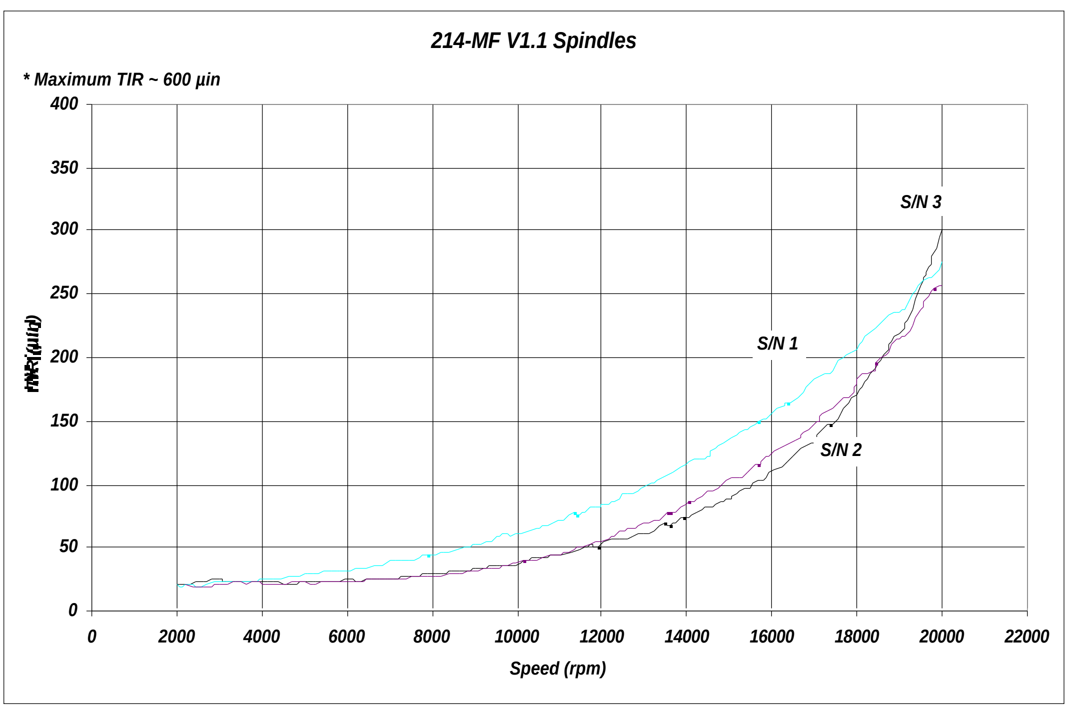

Fig. 2 TIR vs. Speed at 90 psi supply pressure
with 10 disks by using Aluminum Clamp

From Fig. 2, we can see that the eccentricity ratios for the three spindles were between 0.4 to 0.5 up to 20,000 rpm with randomly added twelve (12) disks. After 15,000 rpm the TIR did not increase rapidly, which meant that the design of the air bearings succeed. The aerodynamic property had played sufficient function in the air bearing spindles over 15,000 rpm. The applications of high pressure ratio and step effect commonly used in oil lubricated bearings into air bearings were of importance for enhancing the dynamic performance.

Because of the application of high pressure ratio in the air bearing, the pneumatic hammer was also effectively eliminated, even though there were step pockets in the air bearings.

2.2 Tests with heavier clamps

After the clamp was changed to steel clamp, the instability occurred, Fig. 3.

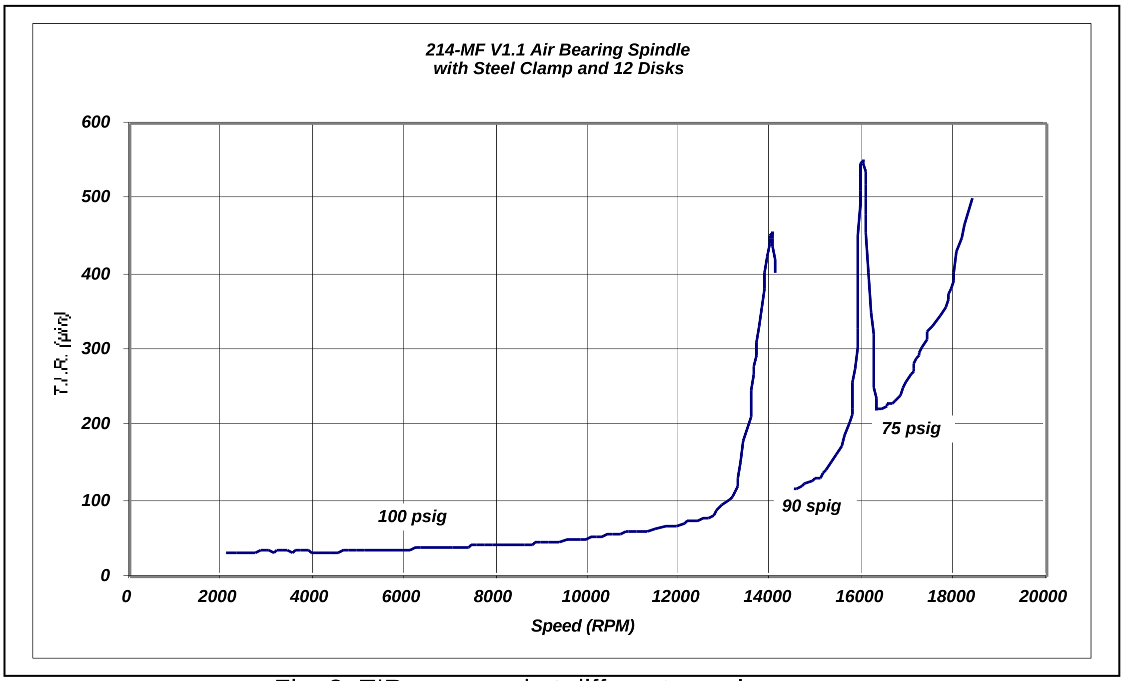

Fig. 3 TIR vs. speed at different supply pressures

When external supply pressure was 100 psi, the speed that instability occurred was ~14,000 rpm. At 90 psi, the speeds of instability were ~16,000 rpm. However, along with the decrease of supply pressure, the TIR increased more quickly because the load capacity was decreased (load capacity is proportional to supply pressure).

Generally speaking, an increase on external supply pressure will increase the stability, because the direction of static force points to the center of bearings to reduce the potential of whirl.

Firstly, we consider the effect of changing clamps. For example, at 90 psi supply pressure, there was not instability by aluminum clamp. But the instability did occur when steel clamp was used. Because of the use of steel clamp, the natural frequency was decreased, and the centrifugal force was increased (because the clamp was not balanced with spindle but centered only). The increased centrifugal force further offsets the center of the shaft from the center of housing. For this bearing with tighter air gap and the larger eccentricity ratio, the aerodynamic force and position angle was increased. The increase on both aerodynamic force and position angle was the major contribution to lead to instability of half speed whirl or resonant whip.

Secondly, we consider the effect of supply pressure on instability. In the studies with the steel clamp, if the pressure was decreased, the speed at which the instability occurred was increased. Based on this analysis, the major reason for this phenomenon was the variation of compensation among the orifices. To understand this phenomenon, consider the effect of orifices at static situation. Due to possible difference of compensation types, each orifice was actually functioning differently along circumferential direction. At higher pressure, shaft was pushed off center. The higher the pressure, the stronger the pushing force was. The shaft position was farther away from the center of bearing housing. The aerodynamic force generated due to the increased eccentricity ratio was increased, which resulted in a larger component force at 90^0 out of phase to the vector of eccentricity. This was the major force to push the shaft to whirl. When the pressure was decreased, i.e. 70 psi, the effect of static force that offset the center of shaft became smaller, thereby increasing the stability.

3. Conclusions

3.1 A design of air bearings with high pressure ratio improved the dynamic performance, leading to higher load capacity and stiffness at high speed. Step effect could be applied into air bearing designs for increasing dynamic performance. The air bearing design with high pressure ratio eliminated the pneumatic hammer.

3.2 The uniformity of compensation is important for air bearing stability.

3.3 Control on imbalance force is a valuable and easy method to control instability.

4. References

[1] Oscar Pinkus, Beno Sternlicht, "Theory of Hydrodynamic Lubrication", McGraw-Hill Book Campany, Inc., 1961

[2] Dudley D. Fuller, " Theory and Practice of Lubrication for Engineers", 2nd Edition, John & Sons, Inc., 1984.

[3] William T. Thomson, "Theory of Vibration with Applications", Prentice-Hall, Inc., 1972

[4] N.S.Grassam, J.W.Powell, " Gas Lubricated Bearings", Butterworths, 1964