KSTLE International Journal, Vol. 3, No. 2, December 2002, pp. 79-83

An Experimental Study on Sealing Improvements of Non-Contact Type Seal for Oil Mist Lubrication

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Abstract: Sealing an oil-air mixture plays important roles to have an enhanced lubrication for high speed spindle. High speed spindle requires non-contact type of sealing mechanism. Current work emphases on the investigation of the air jet effect on the protective collar type labyrinth seal. To improve the sealing capability of conventional labyrinth seal, air jet was injected against through the leakage flow. It has a combined geometry of a protective collar type and an air jet type. Both of a numerical analysis by CFD (Computational Fluid Dynamics) and experimental measurements are carried out to verify sealing improvement. The sealing effects of the leakage clearance and the air jet magnitude are studied in various parameters. The results of pressure drop in the experiment match reasonably to those of the simulation by introducing a flow coefficient. Effect of sealing improvement is explained as decreasing of leakage clearance by air jetting. Thus, sealing effect is improved by amount of air jetting even though clearance becomes larger.

Keywords: Sealing, clearance, oil mist lubrication, non-contact type seal, pressure drop

Introduction

High speed spindles used in high performance machinery employ oil jet or oil mist type lubrication system [1]. Sealing an oil-air mixture plays important roles to have an enhanced lubrication. High speed spindle requires non-contact type of sealing mechanism that prevents a leakage of oil jet or oil mist [2]. In the previous study [2,3], protective collar type labyrinth seal and air jet type seal show more preferable for non-contact types sealing mechanisms working with oil mist or oil jet fluids. Minimum clearance of protective collar type labyrinth seal should be located between inlet side wall and collar, while its size should be minimized taking into account thermal expansions and the deflection of spindle. Therefore this clearance is minimum distance not to be close together physically.

Current work emphases on the investigation of the air jet effect on the protective collar type labyrinth seal. To improve the sealing capability of conventional labyrinth seal, air jet is injected against the leakage flow. In this study, both of numerical analysis by CFD(Computational Fluid Dynamics) and experimental measurements are carried out to verify sealing improvements.

Gas or liquid has been used as a working fluid for most of non-contact type seals including the labyrinth seal [4-7]. However, it is more reasonable to regard two phase flow because oil mist or oil jet are used for high speed spindles lubrication. In this study, working fluid is regard as two phases that are mixed flow of oil and air phase. Both of turbulence and compressible flow model are also introduced in a CFD analysis to represent an isentropic process [8]. Estimation of non-leaking property is determined by amount of pressure drop in the leakage path [9] Sealing effect of the leakage clearance and air jet magnitude are studied for various parameters in experiment.

Structure of sealing enhancement mechanism

Fig. 1 shows a schematic geometry of an applied seal model. It has a combined geometry of a protective collar type and an air jet type seal. Protective collar that makes a minimum clearance between collar and cavity wall is located at the inlet side of cavity. Then air is injected against leakage flow in the minimum clearance. The isentropic process in the clearance is increased because a clearance is reduced by blocking air jet. It makes enhanced sealing performance along with increasing pressure drop. A clearance reduction effect can be expected in this model even though the clearance can not be close together physically anymore. Fig. 2 shows an effect of clearance reduction by a restrict jet. When the air jet is injected into the minimum clearance, the jetting air reduces an effective leakage clearance. This model can achieve excellent sealing performance even though a rotating spindle and cavity has wide leakage clearance unavoidably. In addition, it can control sealing performance by adjusting the jetting air.

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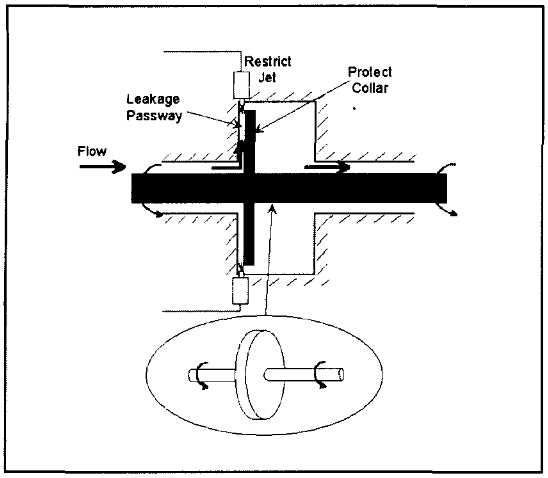


Fig. 1. Applied Seal Model.

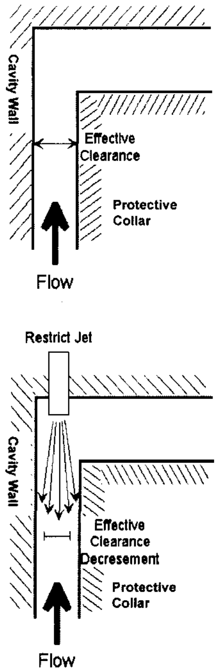


Fig. 2. Effective clearance decreasing.

Testing device for sealing performance

An experimental device is constructed to test sealing performances as shown in Fig. 3. This device has oil mist generating nozzles to make oil mist lubrication environments. Resolution of pressure measurement is 1 Pa. Leakage clearance is adjustable and capable of close together to 0.01 mm. Sixteen air jet nozzles are installed to the circumference direction for the restrict air jet. Precision pressure sensor (measuring resolution of 1Pa) and regulator are installed at the inlet side of the device to measure and control of leakage pressure. A pressure manipulator supplies high-pressure air to the sixteen nozzles.

Testing method and conditions

The pressure drops between inlet and outlet are measured at the speed of 0, 1000, 2000, 3000 rpm to find initial turbulence effects. This test is to find effects of jetting air and spindle rotation speeds without any leakage for the initial turbulence effect. Diameter of collar is 98 mm and end clearance is 2 mm. Face clearances between collar and wall are adjustable to 0.25 mm, 0.5 mm, 0.75 mm, 1.0 mm, 1.25 mm and 1.5 mm to find clearance effects on leakage flow. For measuring pressure drops, jetting pressures are adjusted to 9.8 KPa, 19.6 KPa, 29.4 KPa, 39.2 KPa, and 49.0 KPa to find air jetting effects on constant leakage pressure Initial leakage pressures are ranged from 10 Pa to 200 Pa to find an initial leakage effect on constant jetting pressure. The estimation of non-leaking property is determined by the amount of pressure drop in the leakage path.

Results and discussion

Fig. 4 indicates effect of spindle rotation on constant jetting pressure. This figure is only one case of leakage clearance at

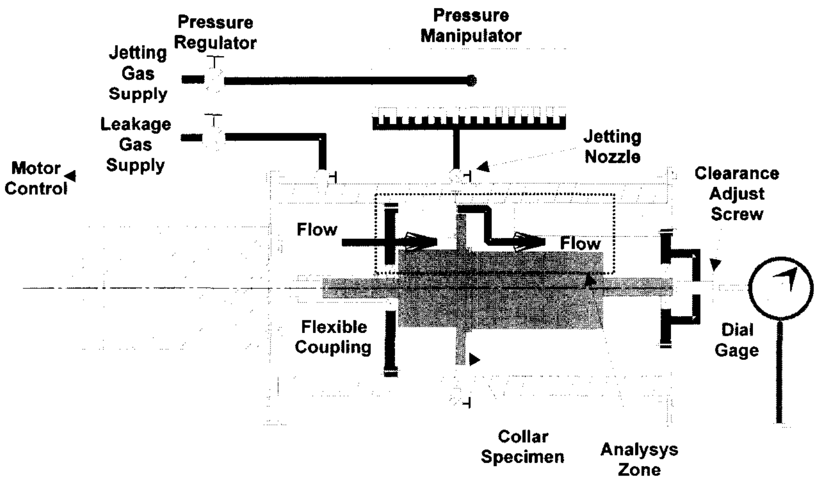


Fig. 3. Performance testing device.

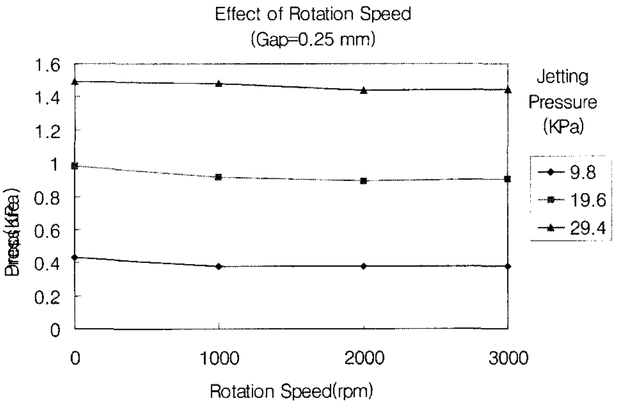


Fig. 4. Effect of rotation speed.

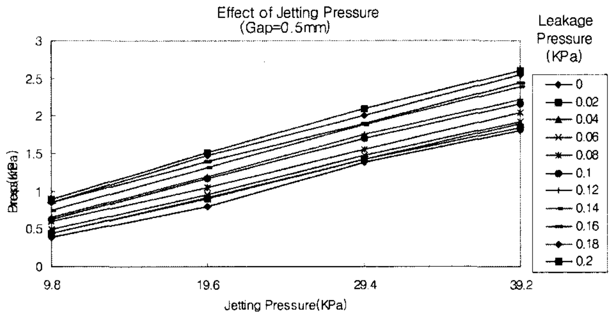


Fig. 5. Effect of jetting pressure.

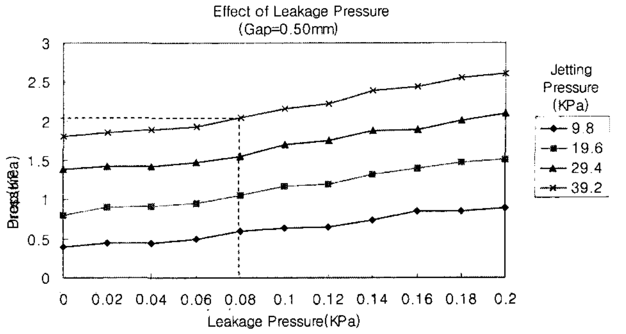


Fig. 6. Effect of leakage pressure.

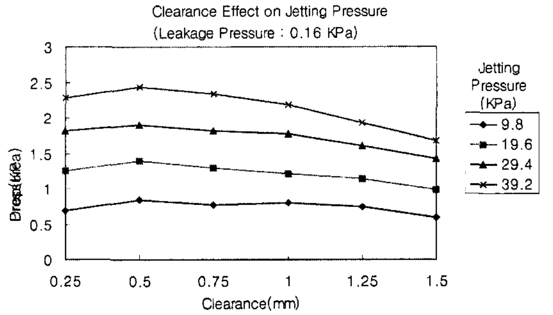


Fig. 7. Effect of clearance.

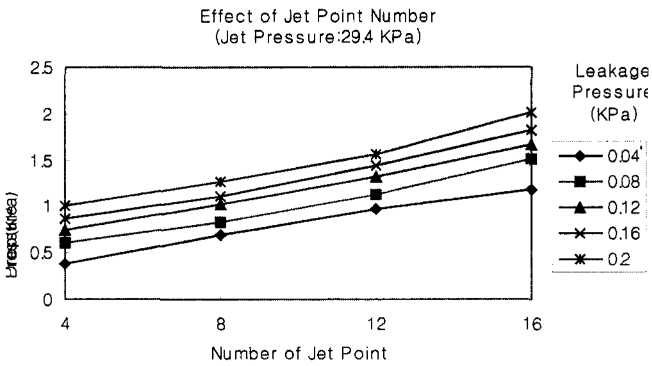


Fig. 8. Effect of jet point number.

0.25 mm while total experiment varies it from 0.25 mm to 1.5mm by a clearance adjusting screw. The result shows that rotation speed is not so much affect to pressure drop. Because of a low density of working fluid, turbulence is fully developed at the beginning of test by air jet and spindle rotation. Therefore increase of circumference direction of rotation speed is not so much affect to pressure drop.

Fig. 5 shows an effect of jetting pressure on constant leakage pressure. In this case, the clearance is 0.5 mm. Leakage pressure, represented here, is proportional to the leakage flow. That means a constant leakage flow occurs at constant leakage pressure at the same geometry. The result shows that increase of jetting pressures increase total pressure drops. Thus, sealing performance is improved by the restrict jet. This is very effective way of sealing enhancement in oil mist lubrication system for high speed spindle.

Fig. 6 shows an effect of leakage pressure on constant jetting pressure. It shows that a quantity of pressure drop increases between inlet and outlet by restricts jet when it has constant leakage pressure. As shown in dot line of Fig. 6, jetting 39.2 KPa of restrict jet generates 2.1 KPa of total pressure drop where the initial pressure drop(the same as leakage pressure) remains as 0.08 KPa.

Fig. 7 shows an effect of leakage clearance on a constant jetting pressure. If a leakage clearance becomes larger, pressure drops decrease, which representing poor sealing performances in ordinary non-contact type seals. However, this figure shows an inverse behavior that increase of clearance makes bigger pressure drop at clearance of 0.25 mm and 0.5mm because of effect of jetting air amount. It shows bigger pressure drop at clearance of 0.5 mm than 0.25 mm. As a diameter of jetting nozzles are 1.0 mm, leakage clearance of 0.25 mm is not enough to send a restrict jet. However, in the case of 0.5 mm leakage clearance, effects of restrict jets become dominant to generate pressure drops. Therefore, the restrict jet can achieve good sealing performance although a spindle lubrication system has large leakage clearance inevitably.

Fig. 8 shows an effect of jet nozzle number (4 to 16) on constant leakage pressure. For an ideal case, line source jet is preferable than any number of point source. However, the line source jet is impossible to practical cases. Therefore the effect of jet point number is investigated as a practical design factor. The effect of jet nozzle number is almost proportional to pressure drop in the range of testing condition. Increase of jet

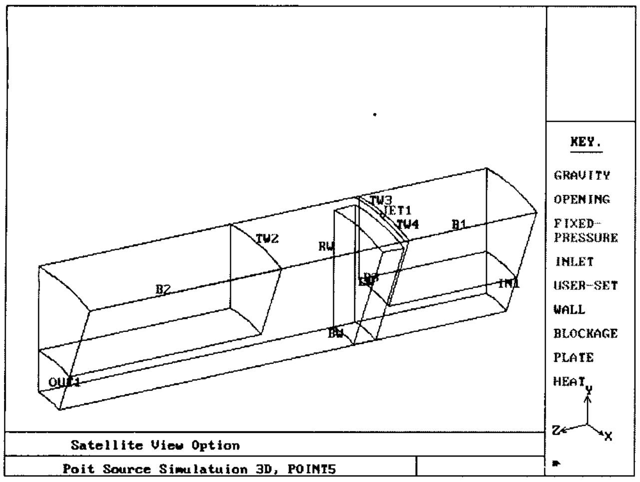
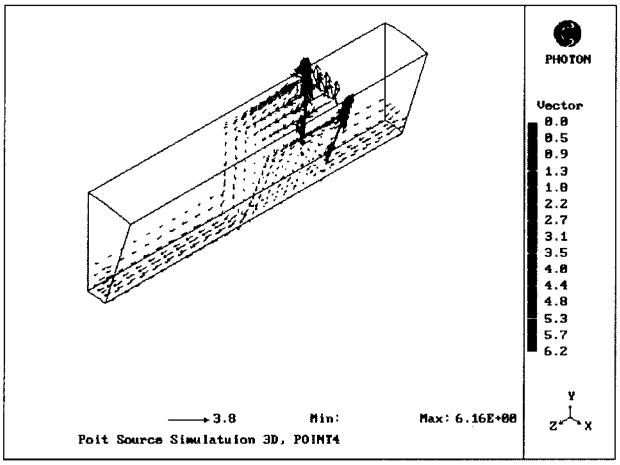
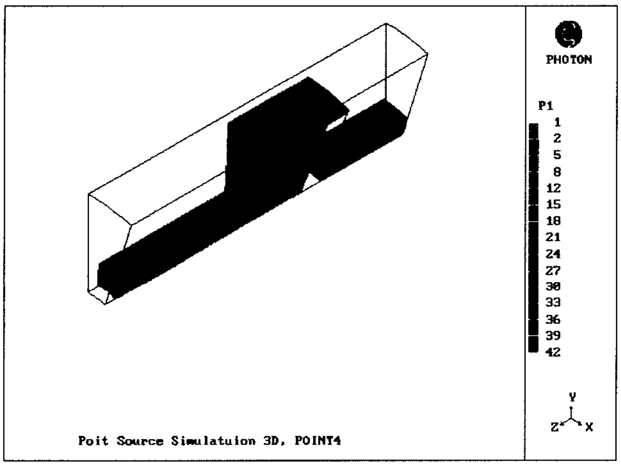


Fig. 9. Geometry of Segment for CFD Analysis.



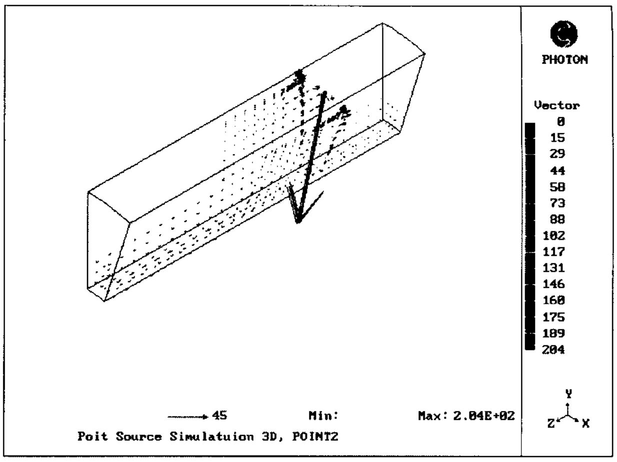
(a)



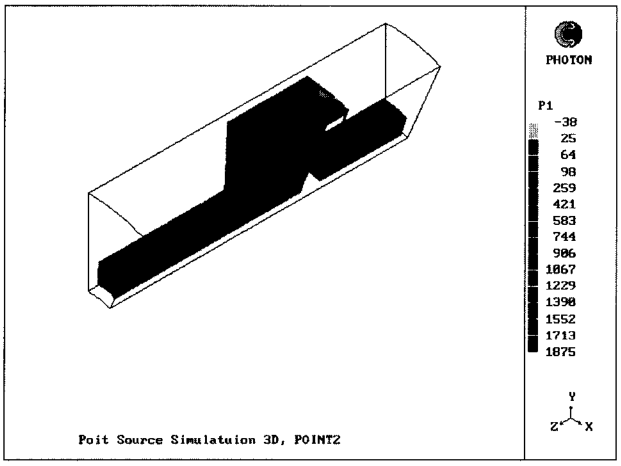
(b)

Fig. 10. CFD result of No jetting case. (a) Velocity Profile (b) Pressure distribution.

nozzle number means an increase of jet flow, thus, sealing performance is improved until it reaches to line source jet condition.



(a)



(b)

Fig. 11. CFD result of jetting case. (a) Velocity Profile (b) Pressure distribution.

Comparison of CFD Analysis

A commercially available CFD code PHOENICS (version 2.1) is used to analysis a flow field in applied seal model. Fig. 9 shows geometrical model of CFD analysis. Working fluid regards as two phase flow as a mixture of air and oil. Two-phase flow means that each phase has different physical properties (i.e., velocity, temperature). Each phase has its own volume, velocity and temperature separately but shares a common pressure. Each phase can transport a such momentum and enthalpy within the flow [10].

Boundary conditions are fitted to the testing equipment, and assuming a divided geometry into 16 segment and each segment has one jetting nozzle. Both of the turbulence and compressible model are introduced in adiabatic condition at 20°C. The initial condition for comparing with experiments is 0.75 mm of leakage clearance and 0.08 KPa of leakage pressure where leakage flow rate is 1.3 l/s and corresponding inlet velocity is 0.536 m/s. Jet pressures are applied to 9.8 KPa, 19.6 KPa, 29.4 KPa and 39.2 KPa as same as the experiment and their flow rates on each nozzle correspond to 0.16 l/s,

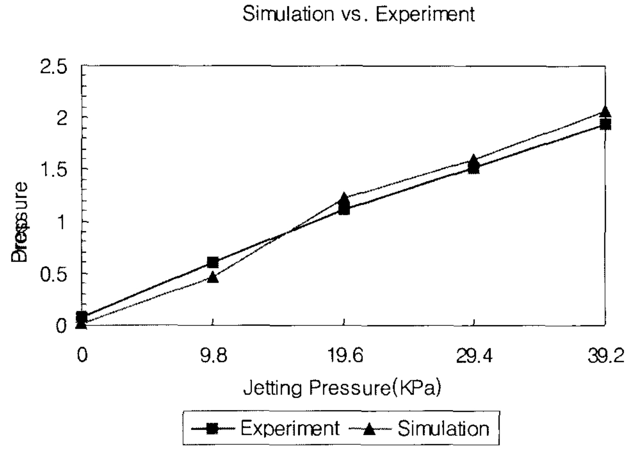


Fig. 12. Pressure drop of simulation and experiment.

0.22 l/s, 0.27 l/s and 0.33 l/s respectively. Jet velocity is calculated according to jet flow rate and applied to CFD analysis as jet velocity.

Fig. 10 show velocity profile and pressure distribution without air jet condition. This figure show that pressure drop mostly occurs at the entrance of minimum clearance between cavity and collar. Therefore, sealing is achieved by flow that passes through the minimum clearance undergoing an isentropic process. Fig. 11 show velocity profile and pressure distribution of air jet applied model. This figure show that pressure drop mostly occurs in the minimum clearance near the jet point. It means reductions of leakage clearance by restrict jet are made and flow undergoes more isentropic process. The applied model generates 1.8 KPa of pressure drop while no air jet condition generates 0.042 KPa of pressure drop. As same results of the experiments, the CFD analysis shows the applied model has excellent sealing performances compare to protective collar type seals without air jetting.

Fig. 12 shows comparison of experiment and CFD results at the condition of 0.75 mm clearance and 0.08 KPa leakage pressure. It compares the relative behaviors of pressure drops for the CFD analysis and experiments. Here, CFD results are fitted to experiments by introducing a flow coefficient. As seen in the Fig. 12, behaviors of pressure drop in experiments and simulation are well match with each other. It verifies an improvement of sealing capability by the restrict jet.

Conclusion

This paper offers a way of performance improvements of labyrinth seal used in a high speed machining center. Performance improvements are verified by experiments and the CFD analysis. An applied model has a combined geometry of a protective collar type and air jet type. Effects of sealing improvement are explained as decreasing of leakage clearance by air jetting. Their sealing characteristics are investigated through experiments of a special testing device. Jet flow, which affects sealing characteristics, should be large to achieve an enhanced sealing. Rotation speed does not affect so much to sealing characteristics on this experimental condition. The restrict jet can achieve good sealing performances although a spindle lubrication system which has large leakage clearance inevitably. Increasing jet nozzle number improves sealing characteristics until it reaches to line source condition. The CFD analysis considers turbulence, compressible and two phase flow to simulates a leakage flow of oil mist lubrication system. Behaviors of pressure drop in experiments and simulation are well match with each other. It verifies an improvement of sealing capability by the restrict jet.

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