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Sealing performance analysis of P –shape seal with fluid pressure penetration loading method

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Abstract. Since cabins must be continuously pressurized during flights, the sealing of cabin doors is a dynamic process. In the whole working process contact states of seals are very complicated, and they change over time. So it is very important to find out separate positions and contact positions accurately to study the leaking of doors. In this paper the surface-based pressure penetration capability of ABAQUS is used to simulate pressure penetration between contacting surfaces of a P-shape seal component subjected to a vertical load and an internal pressure. Information such as deformed configuration and contact stress contours, comparison of fluid pressure and contact pressure is obtained in the analyses. Results show that P-shape seal has a good seal performance. And the analysis of cabin door seals is an important application where pressure penetration effects are important.

1. Introduction

During flights aircraft cabins need to be pressurized to ensure their normal work and activities of persons, which results to large deformations of seals. At the same time, because of air holes on pressurized sides, seals will spring back for the increasing of internal pressure when pressurizing. And it leads to more complex contacts between seals and cabin doors. So it becomes very difficult to accurately determine locations of leakages and then how to accurately apply fluid pressure loads.

At present, researchers have carried out a series of studies on aircraft seals (like tubular seals, petal seals, flat seals, knife seals and P-shape seals). Tan Jing [1] studied a contact fit between O-shape seal rings and cylinder liners, and obtained the influences of contact stresses caused by section sizes, compression rates and radius of cylinder liners. Lee [2] simulated thermal aging phenomenon of lip seals under different working conditions. For rectangular seal rings, He [3] analyzed the effects of temperature and oil pressure on stress and contact pressure. Ke [4] simulated the contacts between pipe seals and metal surfaces so as to predict the gas leakage of tubular seals in a rectangular groove. Ke [5] studied the dynamic friction characteristics of tubular seals and established a slippery model of tube seals. However, the analysis of P -shape seals is seldom because of the large deformation of tubular seals under working conditions, which results to the difficulty of simulation of mechanical properties. For a P-shape seal, because of its asymmetric, it has different mechanical behaviours with symmetrical ones, as Ω-shape seals. So it has a significant practice sense to study the leakage of P-type seals.

In view of the complexity and high cost of determining seal leakage, the surface-based pressure penetration loading is used in this paper to simulate the work of a P–shape seal. With this method critical contact points and separation points can be determined automatically, and locations of pressure leakage can be located.

2. Fluid Pressure Penetration Loading

By defining a "main surface" and a "slave surface", and specifying a starting point which is completely exposed to the fluid, ABAQUS / Standard can simulate the phenomenon that fluid pass through two contacting surfaces. The fluid pressure will be loaded along the starting point to the contact surface, and the direction of pressure loading is normal to the contact surface. When the contact pressure (ccpress) at one node is greater than that of the fluid pressure (ppress), the loading is stopped [6].

As shown in Figure 1, when the ccpress at node 102 is less than ppress, the load will be applied continuously. Conversely, if the ccpress at point 102 is greater than ppress, the load will stop at that point. The advantage of this method is that it can find the critical nodes when contact changes with time, and the simulation results are more accurate.

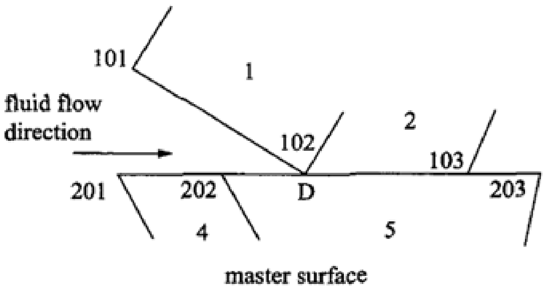

Figure 1. Schematic of theory of fluid pressure penetration loading.

3. Pressure Penetration Analysis of a P-shape Seal

3.1. P-shape Seal Component

A P-shape seal component is made up of a P-shape seal, a compressing piece and a fastener. The schematic of a P-shape seal is shown in Figure 2 from a certain aircraft door seal. Compressing pieces of aircraft doors usually have curved surfaces, which can seal doors by pressing them down.

The compressing to seals is different in different sealing areas. There are usually two types of compressing, one is plane compressing and the other is vertical compressing. For vertical compressing, since the contact area between the compressing piece and the seal is smaller than that of plane compressing, it may lead to a more serious stress concentration during loading. So in this paper vertical compressing is chosen to simulate the working condition of sealing.

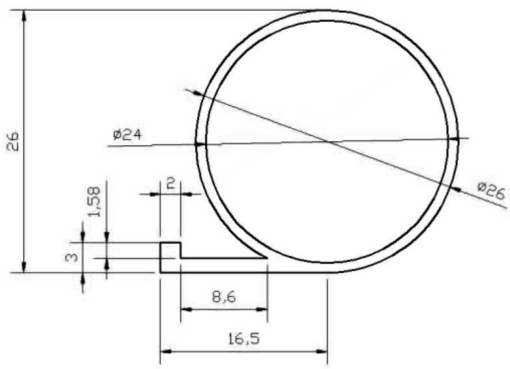

Figure 2. Schematic of a P-shape seal.

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3.2. Material and parameter

The material of seal is a composite material made of fabric and rubber. The fabric layer attached to the surface of the seal and the fabric layer embedded in the seal can increase the stiffness, reduce the deformation, and improve the bearing capacity.

(1) Model and parameter of rubber

For rubber material, two order multi parameter Mooney-Rivilin model is taken for simulation, and material parameters are shown in table 1 [7].

Table 1. Material and parameter of rubber.

Material model	C_{10}	C_{01}
Mooney-Rivilin	0.6861	-0.9479

(2) Model and parameter of fabric

Based on the study of J.R.Cho[8], the fiber material is generally characterized by sub elastic material (Hypoelastic), and the material parameters are shown in table. 2.

Table 2. Material and parameter of fabric.

Material model	Modulus of elasticity (MPa)	Poisson's ratioυ
Hypoelastic	39.2	0.33

3.3. Modeling

(1) Grid

The finite element model is modeled in CATIA according to a true geometric model of a P-type seal. The rubber model uses C3D8RH element, the mesh size is 0.8mm, and the number of elements is 27450. The sealing fastener is set as a discrete rigid body, and the finite element model is shown in Figure 3. The surface fabric layer and the inner fabric layer are modeled by adding shell elements at the surface and in the interior of the rubber model. The shell element models are shown in Figure 4. Tie is used to ensure a better connection between the rubber and the outer fiber layer; embedded is used to connect the inner fiber layer and the rubber. The thickness of the fiber layer is 0.5mm, the same as the true size of a fiber layer in a P-shape seal.

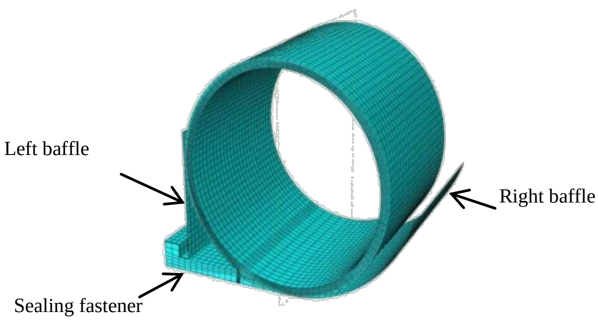
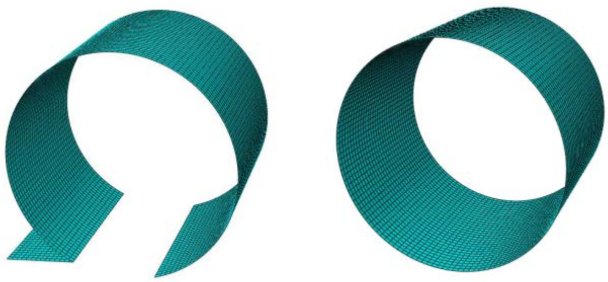


Figure 3. Finite element model of a P-shape seal.



(a) Surface fiber layer (b) Internal fiber layer

Figure 4. Shell element model of fabric layers.

(2) Interaction

A rigid body is established to simulate the vertical compressing piece, as shown in Figure 5. The seal and the sealing fastener are connected by Tie. *CONTACT_SURFACE_TO_SURFACE are used between the seal and the compressing piece, the seal and the left /right encastre. According to Yao Xuefeng[9], the friction coefficient is set to be 0.214 and the model length is 20mm.

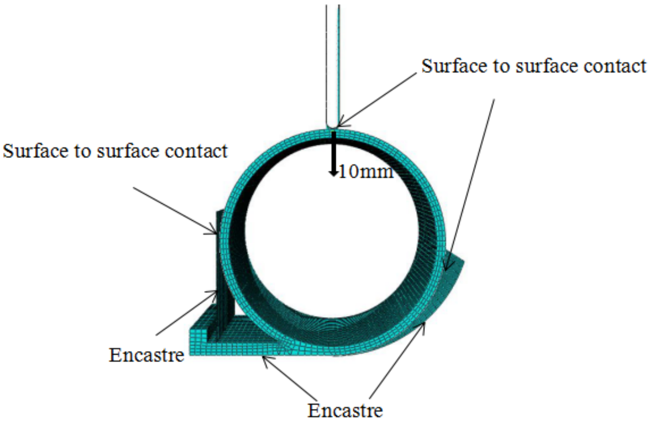


Figure 5. Interaction.

(3) Load

In the first step, a 10mm displacement load is applied to the vertical rigid body in y-direction, simulating the closing of the aircraft door. In the second step a fluid penetration load is applied to simulate the leakage of the seal.

As shown in Figure 6 the fluid pressure load is first applied to the starting point, then extends along the surface of the seal. The fluid pressure is set to be 0.0424MPa, which is the normal working pressure in passenger cabins during flights. When the working pressure is greater than the contact pressure the seal fails, so the contact pressure used to determine the leakage is also set to be 0.0424MPa.

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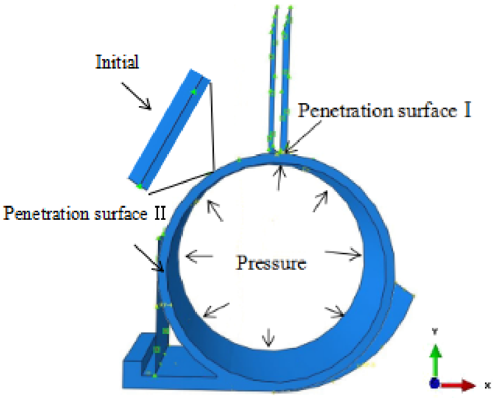
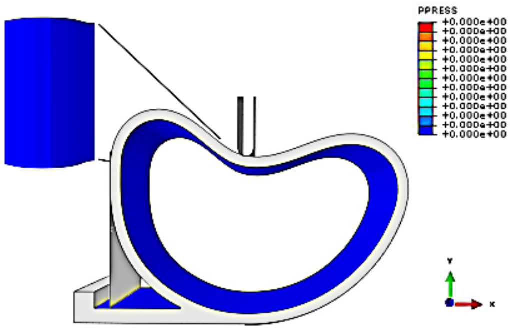


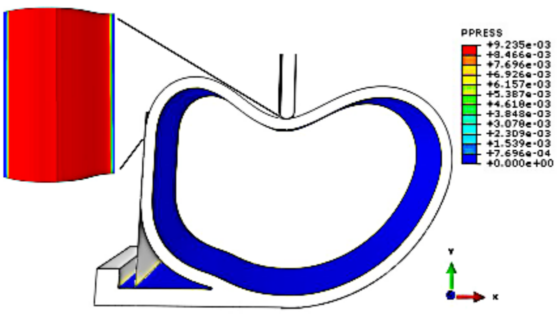
Figure 6. Fluid pressure penetration load.

4. Results

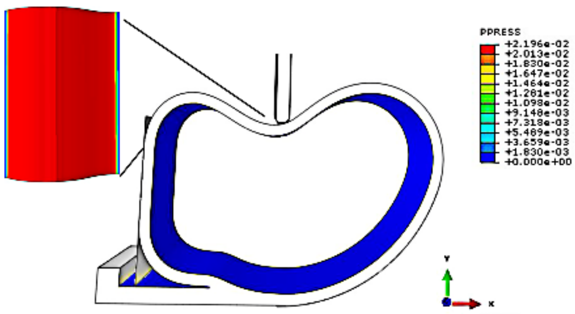
As shown in Figure 8, during the loading, the loading areas that the fluid pressure applies to do not continue to expand, which indicates that the contact pressures in the contact areas are always greater than the fluid pressures, and then we can conclude that the seal performance is good. It is found that the seal is deformed seriously at lower left, which is due to the good contact between the seal and the left baffle. And the deformation is caused by the squeeze of the internal pressure to the seal.



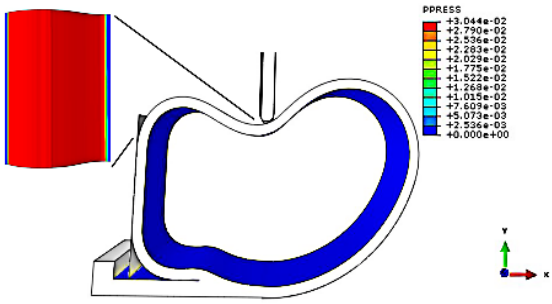
(a) Schematic of 0% loading



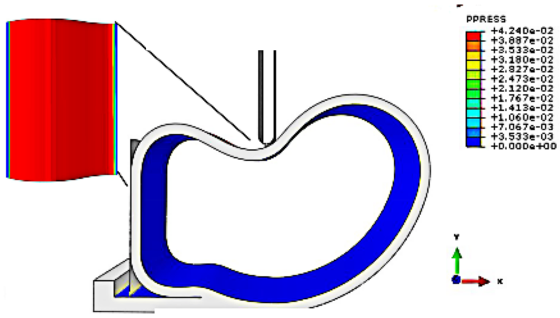
(b) Schematic of 25% loading



(c) Schematic of 50% loading



(d) Schematic of 75% loading



(e) Schematic of 100% loading

Figure 7. Deformed configuration and contact stress contours of the seal.

From the contrast of Figure 8 we can see that when loading up to 100% the contact pressure between the left of the seal and the left baffle reaches 0.067MPa which is greater than that of fluid pressure 0.0424MPa. So there is no fluid pressure on the lower left of the seal, and the seal is squeezed to the left by the internal pressure. With the continual increase of the contact pressure between the seal and the left baffle the seal becomes stronger, and there will be no leakage happen in that position. Meanwhile in the middle part of the upper seal, the contact pressure reaches 0.188MPa, which is much greater than the fluid pressure, and it will not leak out there.

CPRESS at the contact areas before and after pressurization are compared, as shown in Figure 9. The contact pressure increased obviously after pressurization, the maximum value increased from 0.11MPa to 0.63MPa, and the contact pressure distribution changed too. The increase of the contact area at the left baffle indicates that the pressurization can effectively improve contact area and contact pressure, which results to the enhancement of seal performances. At the same time, the maximum contact pressure in compressing region at the middle part is offset, which is related to the pressurization. If the pressure is applied directly on the surface of the seal, the pressure cannot be predicted accurately. Because the offset of the contact position cannot be predicted accurately during the loading, the accuracy of the loading areas is not guaranteed.

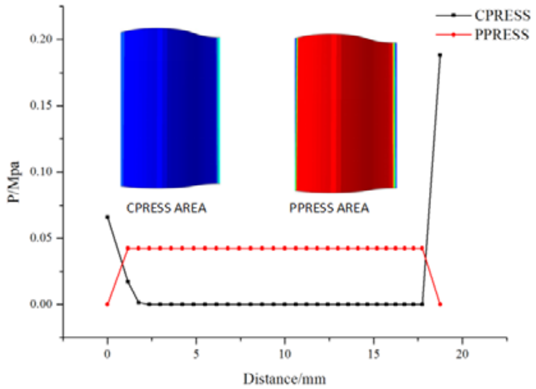


Figure 8. Comparison of fluid pressure and contact pressure.

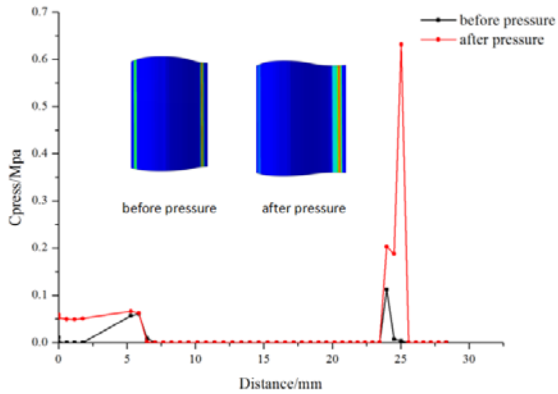


Figure 9. Comparison of contact pressure before and after pressurization.

5. Conclusions

The fluid pressure penetration load in vertical downward direction is applied to simulate the working state of a P-shape seal in a cabin door during flight, the following conclusions are obtained:

(1) Fluid pressure penetration load can effectively show the infiltration process of fluid pressure. By judging the critical value of contact pressure and fluid pressure, it can accurately simulate the pressure differences between inside and outside of doors in working states, which makes simulation results truer.

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(2) By judging the application of fluid pressure, the leakage positions of door seals are analyzed, which provides an effective reference for the prediction of the seal leakage of aircraft doors.

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