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Effect of Rotating Ring Inclination on Single Metal Sealing Performance

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Abstract—**Analysis model of the single metal sealing model was built by using ANSYS software. Under the conditions of high and low pressures, the effect on contact pressure of rotating and stationary ring by the incline angle of rotating ring were analyzed. The result shows that contact pressure of sealing faces of single metal seal is increased gradually from inner to external under low pressure, and contact pressure appears two side peak values and the middle mild distribution under high pressure condition. When the incline angle of tilted face of rotating ring is bigger, the contact pressure of sealing faces is more smaller and the distribution is more mild, sealing performance can be improved effectively**.

Index Terms—**Single metal seal, Finite element model, Contact pressure**

I. Introduction

With the decrease of the oil and gas resources, the exploration and development of oil and gas is being carried out in the deep bottom and deep water. On the condition of deep and ultradeep well, all kinds of drilling tools bear the function of the external pressure drilling fluid. The working life of the rotary dynamic seal directly affects the working life of the drilling tool. Single metal seal is widely used in petroleum, mining, aviation and other fields as a rotary dynamic seal with high temperature resistance, wear resistance and vibration resistance[1]. In 1998, Baker Hughes launched a single metal floating seal SEMS used in roller bit (Fig.1)[2]. In 2003, the company improved and developed a new generation of single metal seal SEMS2 (Fig.2)[3].

At present, many scholars have carried out a lot of researches on the sealing of single metal. Xiong and Richard [4] studied the mechanism of single metal seal in the roller bit. W. Luo and Q.X. He [5] conducted on an experimental research for the SEMS single metal seal. B.S.Zhang et al. [6] used unilateral pressure difference to study the mechanism of SEMS single metal seal by the finite element analysis. J.Sun [7] used finite element method to analyze the stress of SEMS single metal seal under different working pressures. B.S.Zhang et al. [8] improved the SEMS2 single metal floating seal structure through the finite element analysis. Y.Zhang et al. [9] conducted a thermodynamic analysis for the SEMS2 single metal seal under the bilateral filling pressure and different working pressure through the finite element method. The general assembly design and lubrication theory analysis of SEMS2 single metal seal were carried out by Zhang Xiaodong et al. [10]. For the problem of big contact stress change on the surface of dynamic and static ring through internal to external of the SEMS2 single metal seal, this paper takes on the effect on contact pressure of rotating and stationary ring by the incline angle of rotating ring, and the finite element simulation is carried out.

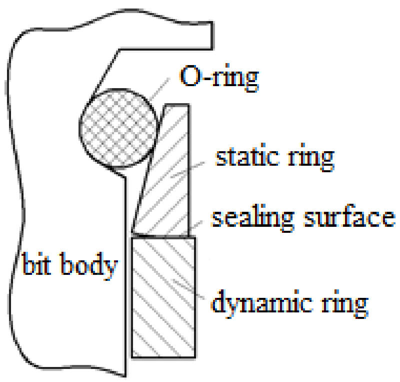

Fig.1 SEMS single metal seal structure

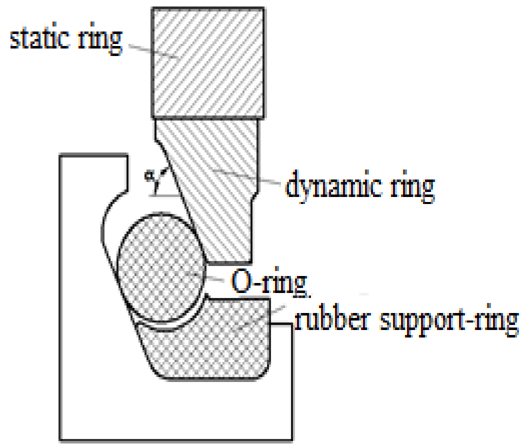

Fig.2 SEMS2 single metal seal structure

II. Finite Element Model of SEMS2 Single Metal Seal and Key Parameters Design

A. *Material model*

In this paper, the SMES2 single metal seal with the inner diameter of 70mm is selected, the O rubber sealing ring and the rubber supporting ring material are NBR butadiene rubber. Because the rubber is a highly nonlinear material, this study assumes that the rubber material has a certain elastic modulus and Poisson's ratio. The tensile and compressive creep properties of the rubber are the same, and the creep does not cause the change of the volume. In this study, the Mooey-Rivilin model of the approximate incompressible elastic material is selected to describe the properties of the super elastic material under large deformation, and its expression is:

$$W = C_1(I_1 - 3) + C_2(I_2 - 3) \quad (1)$$

Where: W is strain energy density, I_1 and I_2 are the first and second strain tensor invariant, respectively. C_1 and C_2 are the material parameters in the Mooney-Rivlin model, respectively.

B. *Key parameters design*

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The contact stress at the interface of the dynamic and static ring is influenced seriously by rubber O-ring, rubber support ring hardness and the incline angle of rotating ring, and the shore hardness value of the rubber O-ring and rubber support ring corresponding to the Mooney-Rivilin parameters [11] are shown in Table 1 below. At the same time, the incline angle α of rotating ring of the single metal sealing is selected as 56°、60°、64°、68°and 72°respectively.

Table1Material parameters of different rubbers hardness

Hardness	Elastic modulus (MPa)	Mooney-Rivilin parameters	
		C_1	C_2
HA70	6.96	1.137	0.023
HA75	8.74	1.444	0.0165

C. *Finite element model and load steps*

The two-dimensional axisymmetric finite element model of SEMS2 single metal seal is established in the finite element software ANSYS, and the model is shown in Figure 3. The elastic modulus of the single metal seal is 2.1E11Pa, Poisson's ratio is 0.3. The material parameters of rubber and elastic modulus E are selected according to table 1, and the Poisson's ratio is 0.499. The plane182 axis symmetry element is selected to be the model element, CONTAC172 is the contact element, and TARGE169 is the target element. The penalty function algorithm is used in rubber contact pair, the friction coefficient is 0.2, and the extended Lagrange algorithm is used in the contact pair of the dynamic and static ring. In the deep and ultra deep well drilling process, the pressure of the external annular flow channel is constantly changing because the downhole dynamic drilling tool and the drilling tool are in different well depth. The internal lubrication oil pressure and the external annular drilling fluid pressure difference is about 0.3 ~ 0.5MPa, so the internal and external pressure difference is chosen as 0.3MPa. The constraint of the Y direction of the main body is the boundary condition, and the load step is mainly included the two steps which is shown in Table2.

Table 2 Load steps of SEMS2 single metal seal

Load steps		External annulus pressure	Internal lubricating oil pressure
First step		Axial assembly compression 1.5mm	
Second step	Low pressure	3MPa	3.3 MPa
	High pressure	30 MPa	30.3 MPa

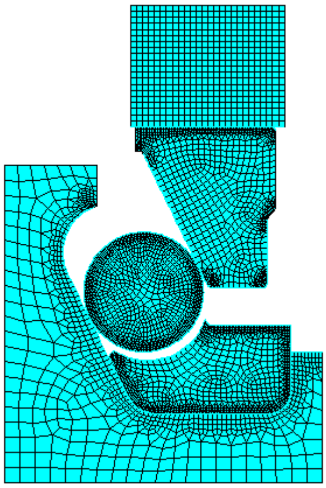
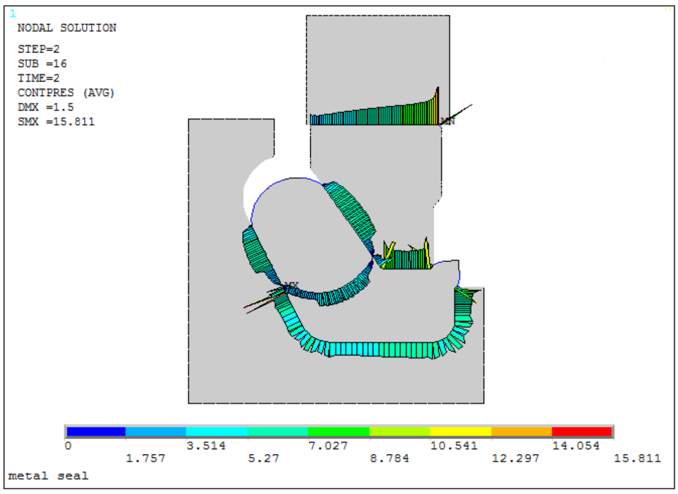


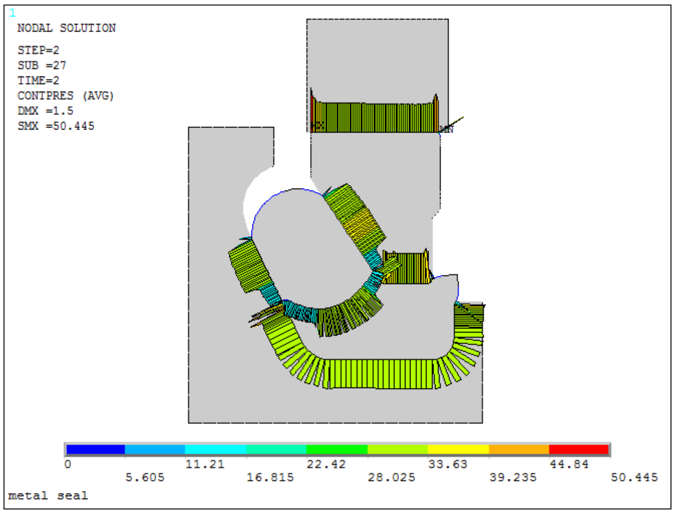
Fig.3 Finite element model of single metal seal

III. THE INFLUENCE OF KEY PARAMETERS ON THE CONTACT STRESS OF THE DYNAMIC AND STATIC RING

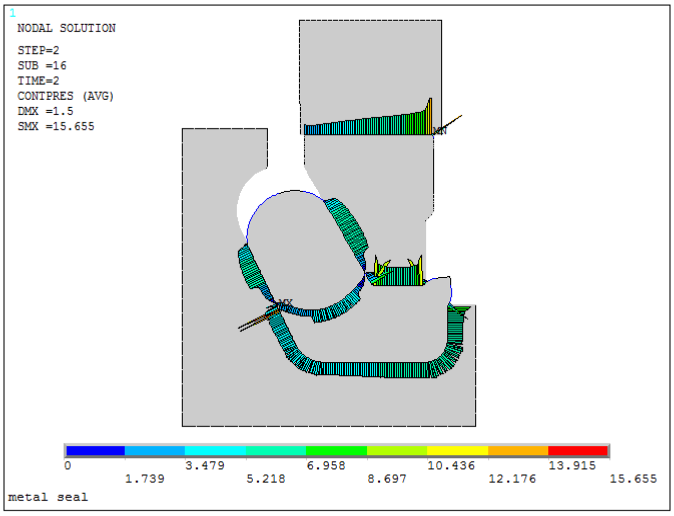
The contact stress of the end face of the dynamic and static ring directly affects the seal state of the single metal seal. Therefore, controlling the contact stress of the end face of the single metal seal and improving the distribution state can effectively reduce the wear of the end face of the single metal and improve the sealing performance. The hardness of the single metal seal O-ring and rubber support ring is set to be HA70, and the change of contact stress on the end face which is caused by the the incline angle of rotating ring is studied under the condition of low pressure (3Mpa) and high pressure (30Mpa). The contact stress nephograms are shown as follows:



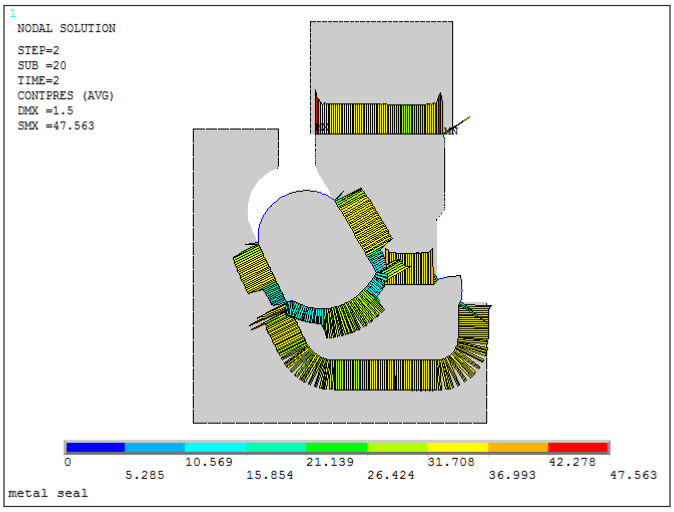
a（α=56° P=3Mpa）



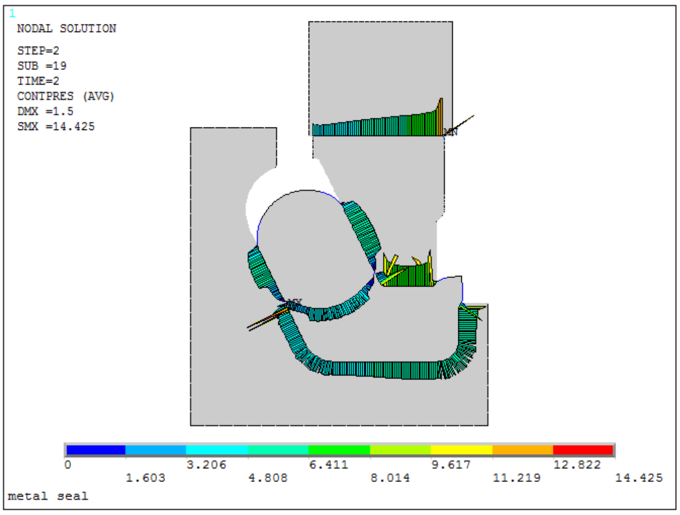
b（α=56° P=30Mpa）



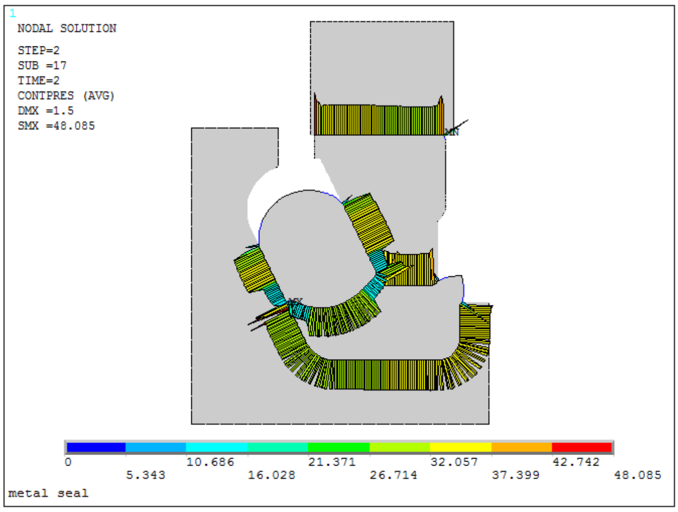
c（α=60° P=3Mpa）



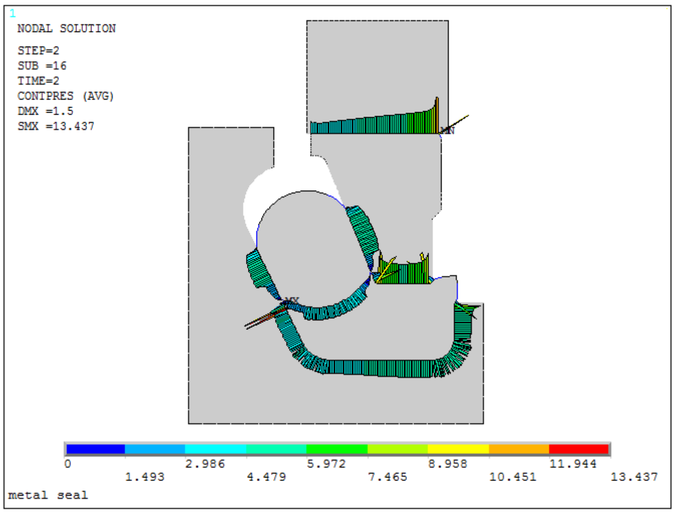
d（α=60° P=30Mpa）



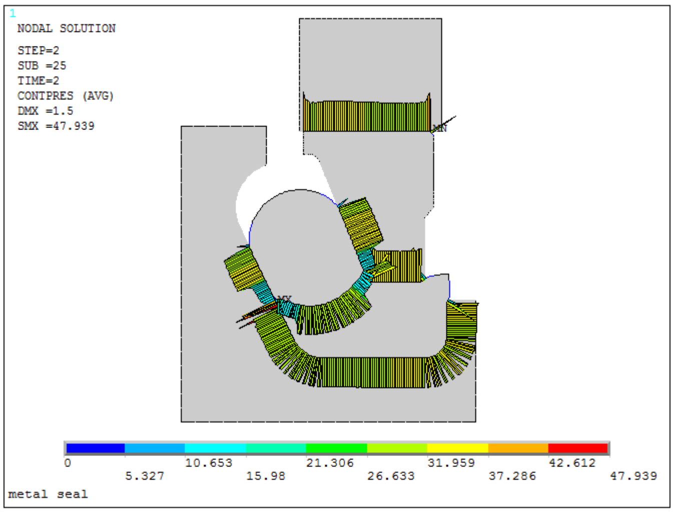
e（α=64° P=3Mpa）



f（α=64° P=30Mpa）



g（α=68° P=3Mpa）



h （α=68° P=30Mpa）

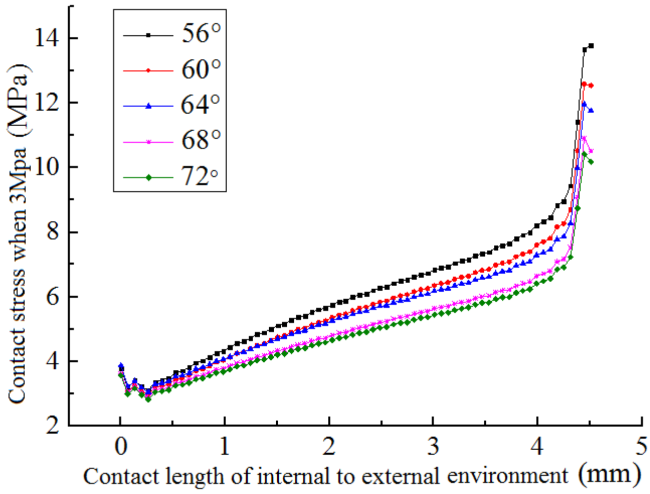
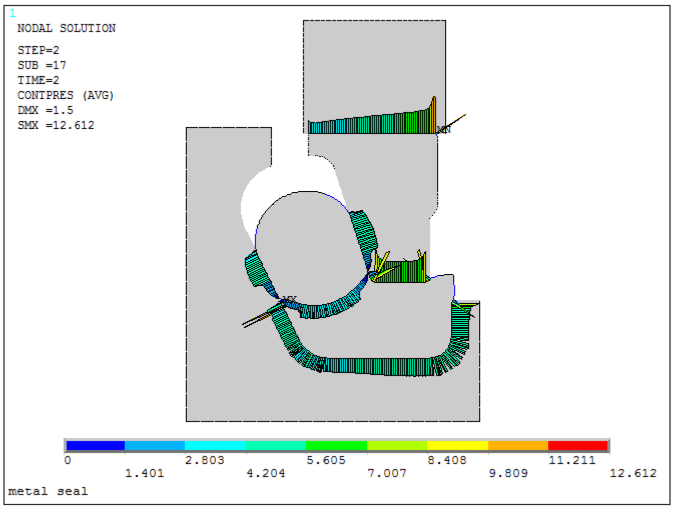


Fig.5 Effect of incline angle on contact stress under low pressure



i （α=72° P=3Mpa）

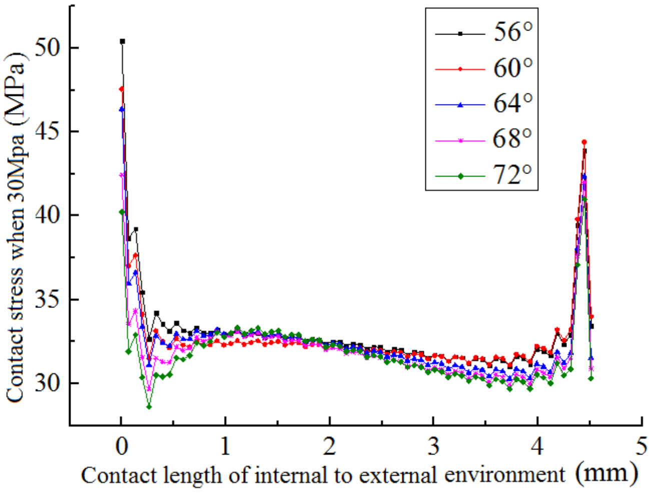
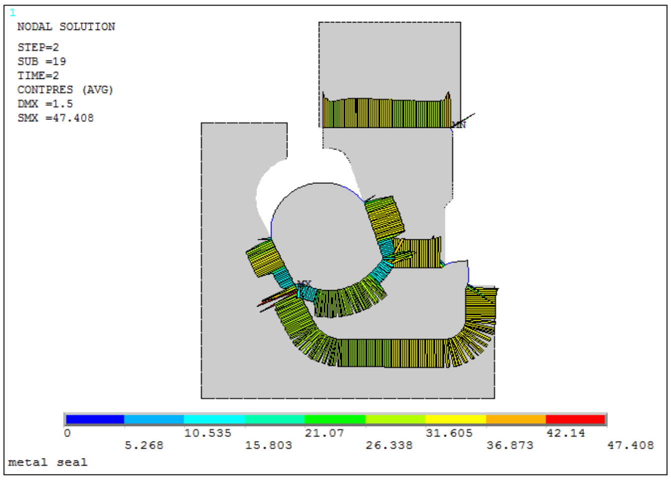


Fig.6 Effect of incline angle on contact stress under high pressure



j （α=72° P=30Mpa）

Fig.4 Contact stress corresponding to different parameters

The contact stress change curves of the dynamic and static ring are shown in Figure 5 and Figure 6.

From the above, we can get that the contact stress at dynamic and static ring is small and lateral contact stress is higher than that on the inside under different ring tilt angles and in the condition of low pressure. At the same time, the slope of the curve is relatively small, which declares that the smaller the contact stress increasing rate along the contact length between the internal and external directions is. In high pressure conditions, the interior and lateral obviously appear peak contact stress and internal contact stress value is higher than the external side, and the contact stress of the middle section decreases gradually along the contact length direction. The contact stress distribution at both ends of the dynamic and static ring increases with the inclination of the inclined plane, and the increase amplitude of the contact stress at the middle position is relatively small. When the incline angle of rotating ring is 72°, in the condition of low pressure the contact stress values are relatively small along the length direction of the contact stress and changes in a small range, while in the high pressure conditions, the peak contact stress of the two ends and the intermediate contact stress values are relative smaller than other angles.

IV. Conclusion

The finite element analysis of the contact stress of the SEMS2 single metal seal with ANSYS software is carried out. The influence of the inclination of the rotating ring on the stress state of the dynamic and static ring under the condition of low pressure and high pressure are discussed respectively. Through the analysis, the following conclusions are drawn:

(1) In the low pressure condition, the contact stress of the dynamic and static ring along the contact length is gradually increased, and the contact stress is maximum near the outer annular drilling fluid while the contact stress close to the internal lubricating oil is minimum. In high pressure condition, the peak value of contact stress of the ring is at the inner and outer sides, and the contact stress in the middle of the contact area is relatively small and the change is not large.

(2) When the incline angle of rotating ring increases, the contact stress value and its change range of the dynamic and static ring are relatively reduced under low pressure condition. Under high pressure, the contact stress changes little in the middle of the contact area and the peak value at both ends is relatively reduced. Therefore, in the case that the length of the axial contact area of the dynamic and static ring is not reduced, the incline angle of rotating ring is increased, which is beneficial to improve the working life of the seal and reduce the surface abrasion.

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