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Cone bit bearing seal failure analysis based on the finite element analysis

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ABSTRACT

Failure analysis of cone bit bearing seals is important in reducing production cost and preventing in-service component failure. However, a generally accepted criterion for their failure has not yet been established because of complexities in both their material properties and the environment. In this study, a two-dimensional axisymmetric finite element analysis (FEA) numerical model was established. FEA software was developed based on the Mooney–Rivlin constitutive model of the rubber material, and the penalty function contact algorithm. The distributions of stress, strain and contact pressure were analyzed to establish their effect on failure. The locations and causes of the failure and preventive measures were determined by comparison with an actual failure case. It was found that stress concentration and uneven pressure distribution occur at the seal. Rubber rings are highly and unequally compressed. Metal ring structure mainly determines sealing performance. To reduce the occurrence of failure, the structure must be improved by: designing an appropriate angle-tapered metal ring end face structure instead of a plane to change the trend in pressure distribution, increasing the contact area of the metal ring end face to reduce contact pressure and make the contact pressure distribution more uniform to reduce sealing surface wear, reducing the radial thickness to reduce the compression of the rubber ring, and improving back support structures to reduce the stress concentration. Results from the study can prevent and minimize risk for future failures to increase bit life and reduce drilling costs.

1. Introduction

Bearing seals are a critical and vulnerable part of the cone bit, as seal performance affects the service behavior of the bit directly and has an important impact on production safety and the economic benefits of drilling [1–3]. Eighty percent of bit failures result from early bearing damage. Bearing life depends extensively on seal life and 30% of bearing failures occur because of early seal failure [4]. Consequently, bearing seal life should be extended to promote cone bit life.

Rubber O-rings were used initially as cone bit bearing seals. These then evolved to a series type of seal rings, which were widely used but became badly damaged and had short lives [5]. In 1987, the Baker Hughes Christensen Company introduced

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bimetal floating seal structures into the cone bit bearing system. Compared with conventional rubber seals, a remarkable increase in both rotary speed and life were observed. In 1998, Baker Hughes released the first generation single-energizer metal seal (SEMS) cone bit. These bits were characterized by a back support rubber ring and were used in the Gulf of Mexico (GOM) area with an average life of more than 55 h [6]. In 2003, these bits were improved by Baker Hughes to the second generation SEMS. Statistical research showed that, compared with conventional radial rubber seal and SEMS bits, an increase of 47% and 38% average working revolution, respectively, was achieved using the second generation SEMS cone bit [7,8]. In 2009, Griffo developed a rubber seal with fiber technology containing nanoparticles to improve cone bit working performance [9]. In the early 1990s, Luo et al. designed a single metal floating seal structure to promote seal performance and bit reliability [10]. In 2009, plasma spraying technology was applied on the metal floating seal ring surface and by using WC–Co, surface wear ability and bit life were enhanced [11]. In 2010, Zhang improved the second generation SEMS with a custom-shaped rubber seal ring instead of the rubber O-ring and a support ring to reduce friction between the seal ring and the axle journal [12]. A significant amount of research has therefore been conducted on cone bit bearing seals involving improvements in structure, the selection of optimal material, surface engineering technology, and finite element simulation. However, a generally accepted criterion for their failure has not yet been established because of complexities in both their material properties and the environment. Failure studies on bearing seals could promote seal performance and bit life significantly. Finite element analysis (FEA) is a powerful tool for evaluating the failure and performance of a seal.

Therefore, the objective of this research is to establish the major causes and locations of failure damage of bearing seals by the FEA method. Recommended actions to prevent and minimize risk for future failures are also considered.

2. Seal structure

Fig. 1 shows the typical bimetal cone bit bearing seal structure located in a chamber between the roller and bearing. According to its function, it can be termed an axial full-floating unbalanced bimetal ring mechanical seal. The term axial means that the seal face is vertical to the axial line. Full-floating means that both the static and moving rings vibrate axially and radially, while floating in the seal chamber. Their sealing faces are attached tightly under working conditions, thereby building up the axial seal while not touching the seal chamber. Unbalanced means that the maximum seal pressure on the seal face exceeds the inner-outer differential pressure of the seal chamber. The two high elastic seal rings always keep the two metal seal ring faces in contact, thereby forming a reliable seal, and also play the role of radial seal. This seal possesses excellent high-temperature resistance, wear resistance and can adapt to high-speed drilling.

3. Working pressure difference of the seal

The pressure difference, Δp, between the drilling fluid and the grease on both sides of the seal must be determined before conducting the simulation analysis. At rest, the role of the cone bit is to balance the system pressure; the pressure exerted by the grease in the bit seal chamber balances that of the external drilling fluid and Δp is zero. When the bit drills, the volume of the bearing cavity changes. This is caused by vibration of the bearing system, and pressure exerted by the grease as a result of thermal expansion by frictional heat results in an increase in Δp. Values for Δp were found to range from 0.3 to 0.5 MPa from the simulation test [13], and Δp_{max} was 0.7 MPa as measured downhole [14].

4. Hyperelastic constitutive model of the rubber material

The rubber ring material can be considered to be a hyperelastic material, and it exhibits highly nonlinear elastic isotropic behavior with incompressibility [15]. A relationship between stress and strain in the hyperelastic material, generally

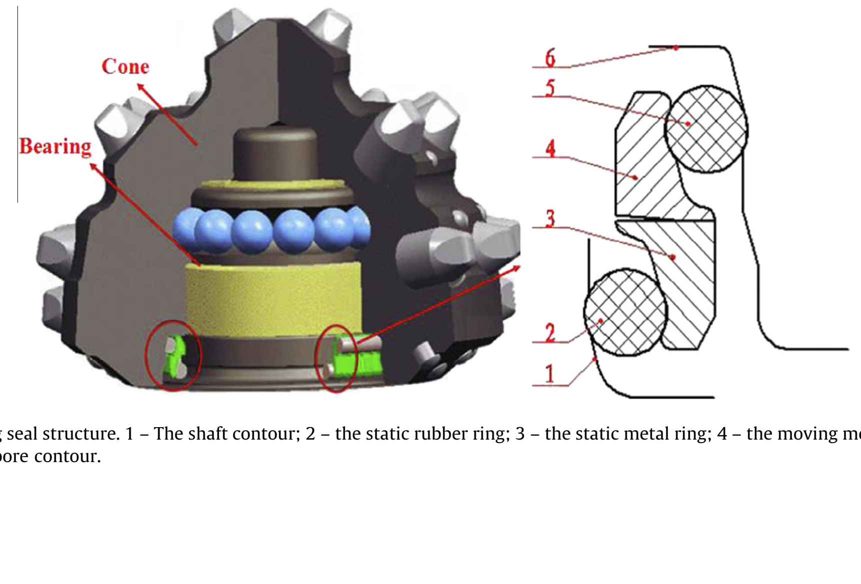

Fig. 1. Cone bit bearing seal structure. 1 – The shaft contour; 2 – the static rubber ring; 3 – the static metal ring; 4 – the moving metal ring; 5 – the moving rubber ring; 6 – cone bore contour.