ROCK BIT METAL BEARING SEAL TECHNOLOGY

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ABSTRACT

This paper describes new rock bit bearing seal technology that is just beginning to be applied to difficult drilling applications in West Texas. The conventional elastomer seal may have limitations in applications where there is elevated temperature, oil based mud, or high bit rotary speed. The use of hard metal rather than an elastomer as the primary sealing element improves bit performance in these environments. High temperature, oil mud and high RPM associated with downhole motor drilling are present in horizontal drilling in the Williston Basin of North Dakota. The results of testing metal seals in Williston Basin horizontal drilling are presented along with recent metal seal performance in West Texas. Metal seal bits have shown to be much more reliable and consistent than elastomer seal bits in these applications. Longer hours and higher reliability have reduced the number of bits required and thus lowered the cost of wells drilled. The improved percentage of seal effective bits has also lowered the risk of costly fishing jobs due to bearing failure.

INTRODUCTION

The advent of metal seal technology in roller cone bits offers a superior alternative to conventional elastomer bearing seal designs when operating at high rotary speed and/or in elevated temperature or highly abrasive environments. This new technology, which is just beginning to be applied to difficult drilling applications in West Texas / New Mexico, has been successfully applied in horizontal drilling in the Williston Basin of North Dakota. The Williston Basin has been linked with inconsistent seal life for years due to elevated downhole temperatures and oil mud environments. This problem is accentuated by the high RPM associated with the use of downhole motors in directional/horizontal work. The elastomer o-ring seal used in the journal bearings of rolling cutter bits may have limitations in these applications whether in a build, tangent or lateral section. Metal seal bits have proven to be much more reliable and consistent in this type of drilling.

ELASTOMER SEALS

For two decades the o-ring bearing seal has been the standard of the rock bit industry. The o-ring and other similar elastomer bearing seals are positioned at the outer end of the rock bit bearing as shown in Figure 1. These elastomer seals are compressed radially between the cone seal gland and head journal as detailed in Figure 2. As the bearing rotates, the radial compression on the seal maintains leak-proof contact between head and cone seal glands.

The life expectancy of an elastomer seal is influenced by many factors, including seal material properties, bit operating parameters and bit environment. A critical property of an elastomer seal is wear resistance. Wear resistance depends on the tensile strength of the elastomer (Burr, 1979) which decreases with increasing temperature as illustrated in Figure 3. Two sources of potentially seal damaging heat are self-generated frictional heat and the downhole temperature encountered by the bit. Relatively high frictional drag between the steel and elastomer seal results in a rise in seal heat generation with increasing sliding speed, or bit rotary speed. At high bit RPM (usually 150+ RPM), as often found when downhole motors are used, sufficient seal frictional heat is generated to significantly reduce seal life.

METAL SEALS

For many years large mechanical rotary seals with lubricated metal to metal faces have out-performed elastomer seals in harsh environments and at high rotary speeds. Seal space limitations generally prevented their use as bearing seals in roller cone rock bits.

A new, small cross section, compensating metal to metal face seal has been developed for use in rolling cutter rock bits. This metal seal design is illustrated in Figure 4. The new seal consists of two hard metal alloy seal rings supported by two elastomeric energizers (o-rings). All dynamic sealing is accomplished at the metal ring faces that are in lubricated sealing contact. The energizers serve as static seals and urge the opposing metal ring faces into sealing contact. This metal seal design is able to compensate for changes in volume of the space occupied by the lubricant near the seal which are caused by axial cone motion (Burr, 1985). The seal accomplishes this dynamic volume compensation by the ability of the metal rings to move together axially while the energizers roll slightly. This lubricant volume compensation prevents potentially seal damaging pressure surges in the lubricant near the seal.

Seal frictional drag between the polished and lubricated metal ring faces is 70% to 80% lower than the frictional drag of the conventional elastomer seal.(Schmidt et al, 1991) This makes it possible for the metal seal to operate at higher rotary speed with less seal generated heat. Frictional heat generated by the metal seal at high RPM is more efficiently conducted to the surrounding fluids because the thermal conductivity of the metal rings is higher than that of an elastomer.

The elevated temperatures (250° F - 500° F) that may be encountered in areas with a high geothermal temperature gradient have relatively little effect on the hard metal alloy seal rings. Although they are elastomers, the energizers are static seals and wear resistance is not of prime importance. The elastomer used in the energizers has been selected for maximum temperature and chemical resistance. This gives the metal seal the ability to operate longer at higher temperatures than elastomer seals.(Burr and Jarding, 1990)

Wear resistance is important in any type of seal design. The hard metal seal rings are more resistant to abrasive wear caused by transported cuttings than elastomer seals. Metal seal bits may be used to extend seal life when high solids drilling fluids are used. In the new condition, the faces of the metal seal make contact with each other forming a sealing band on the mud side as shown in Figure 5a. The tapered gap on the lubricant side of the faces provides a lubricant passage to the sealing band. As the seal wears, this sealing band moves inward across the seal faces as shown in Figure 5b. The seal face geometry is designed so the seal band remains a constant width as it moves across the seal face. As abrasive wear gradually reduces the outside diameter of the sealing band, adhesive wear between the two ring faces causes the sealing band inside diameter to decrease. These two wear mechanisms are inter-related through the seal band contact pressure. The decreasing width of the seal band caused by abrasion increases contact pressure, thereby increasing adhesive wear and increasing seal band width inward. Figure 6 compares a pair of seal faces in the new condition with a pair from a bit run in the North Sea for more than 126 hours at 150 - 274 RPM for a total of 1.8 million bit revolutions.(Schmidt et al, 1991)

DIRECTIONAL/HORIZONTAL DRILLING IN THE WILLISTON BASIN

A field performance study was made on 8-3/4" elastomer seal and metal seal bits run during 1990, based on available run information and dull grades. All bits included in the study were run on motors in the Williston Basin of western North Dakota and eastern Montana. The wells in the study were drilled with oil mud. High torque/low speed 6-3/4" motors were generally used which resulted in approximately 200 RPM at the bit. Steerable systems were used in the lateral and tangent sections while fixed angle build systems were used for the build sections. All data was taken from the Bakken Shale horizontal wells where the build takes place through the Lodgepole Limestone. All cutting structures were IADC 5-3-7. Since all elastomer seal and metal seal bits were run under the same average parameters, the penetration rates remained fairly constant and the cutting structures were pulled with similar dull grades (very little damage). Therefore, the limiting factor for rolling cutter rock bits in this motor application was seal/bearing life.

Table 1 shows the average hours and percent of effective seals for the metal seal and elastomer seal bits. Overall, the metal seal bits drilled for 35% more hours with 47% less seal failures. A study of one major operator using both elastomer seal and metal seal bits produced similar results as shown in Table 2.

An example of drilling cost savings per hole for the data in Table 2 is given in Table 3. The costs are based on an average of 200 hours from kickoff to TD, $550/hr rig and motor cost and $300 per 1000' trip cost. The use of metal seal bits instead of elastomer seal bits results in a decrease of 1.5 bits and trips per hole. This translates to a 5.2% savings of $8742 per hole if all drilling parameters remain unchanged.

Greater savings may be achieved if the operator is willing to take advantage of the higher seal effective rate and the unique high RPM capability of the metal seal. Assuming the normally accepted penetration rate response to RPM (Woods, 1969), an increase of 20 to 30 RPM would approximately double the cost savings with only slight increase in risk of seal failure.

A reliability analysis (Kelly, 1990) of the data for the metal seal bits and the three most popular elastomer seal bits resulted in the curves shown in Figure 7. Reliability (on the left side) or risk (on the right side) is plotted as a function of total bit revolutions. This graph clearly illustrates the high survival rate of metal seal bits compared to the elastomer seal bits used in horizontal wells drilled in the Williston Basin.

WEST TEXAS / NEW MEXICO

Difficult drilling applications in the Permian Basin will benefit from metal seal rock bit technology. All of the severe downhole environments and operating parameters, which may push elastomer seals beyond their limits, exist here. High RPM and/or motor applications, elevated temperatures, diesel and oil muds, and use of abrasive or high solids content muds are all conditions in which metal seals are more reliable than elastomer seals. Two metal seal bits have been run recently in West Texas / New Mexico. A 12-1/4" IADC 547 metal seal bit was run for 131-1/4 hours at 50/55,000 WOB and 65/60 RPM (481,575 bit revolutions) and was pulled at TD with effective seals. A 12-1/4" IADC 537 metal seal bit was run for 54-1/2 hours in a diesel mud below 17,000 feet at 35,000 WOB and 140 RPM (457,800 bit revolutions) and was pulled with effective seals.

CONCLUSIONS

Metal seal bits have superior reliability, longer hours and a higher seal effective rate compared to elastomer seal bits run in the difficult horizontal drilling of the Williston Basin. These performance advantages should be realized in other areas such as West Texas / New Mexico, where difficult drilling conditions push elastomer seals beyond their limits.

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Table 1
Metal Seal and Elastomer Seal Bit Performance - Williston Basin

SIZE	TYPE	NO/BITS	AVG HRS	% SEALS EFFECTIVE
8-3/4	METAL SEAL	23	35.8	73.9
8-3/4	ELASTOMER	155	26.5	50.3

Table 2
Metal Seal and Elastomer Seal Bit Performance - Williston Basin - One Major Operator

SIZE	TYPE	NO/BITS	AVG HRS	% SEALS EFFECTIVE
8-3/4	METAL SEAL	10	37.2	80.0
8-3/4	ELASTOMER	117	28.9	57.3

Table 3
Cost Calculations for Metal Seal and Elastomer Seal Bits

METAL SEAL BITS				
200 HRS	X	$ 550/HR	=	$110,000
5.4 BITS	X	$5540/BIT	=	$ 29,916
	TRIP COST	(12,000' AVG)	=	$ 19,440
		TOTAL	=	$159,356
ELASTOMER SEAL BITS				
200 HRS	X	$ 550/HR	=	$110,000
6.9 BITS	X	4820/BIT	=	$ 33,258
	TRIP COST	(12,000' AVG)	=	$ 24,840
		TOTAL	=	$168,098

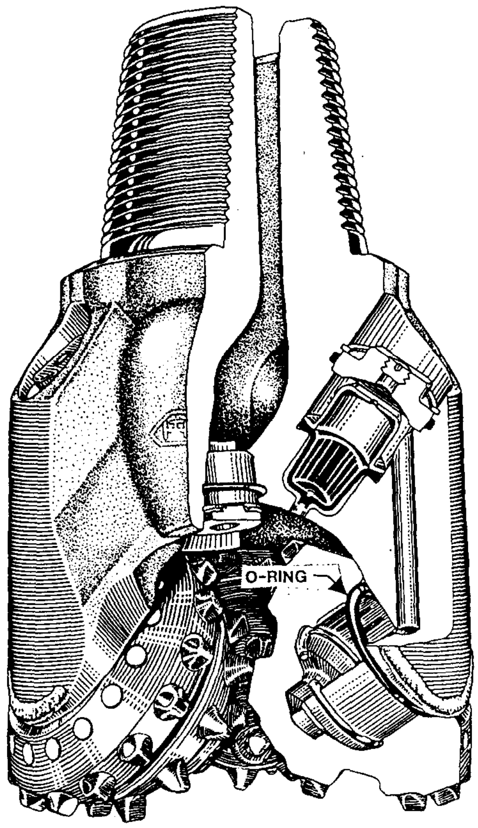

Figure 1 - Rock bit O-ring bearing seal

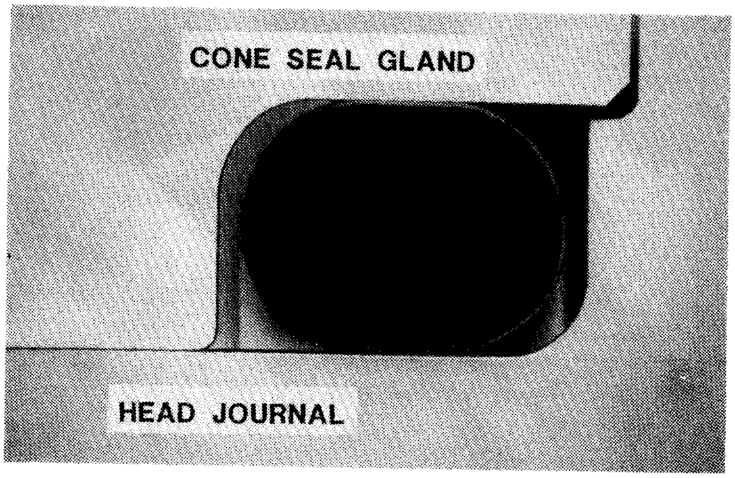

Figure 2 - O-ring cross section

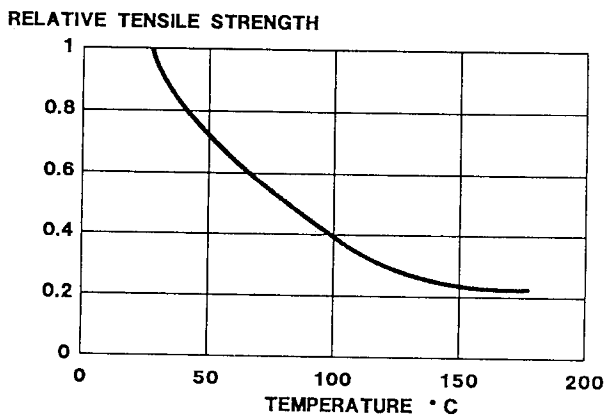

Figure 3 - Tensile strength versus temperature for a typical rock bit o-ring seal (after Kelly and Ledgerwood, 1988)

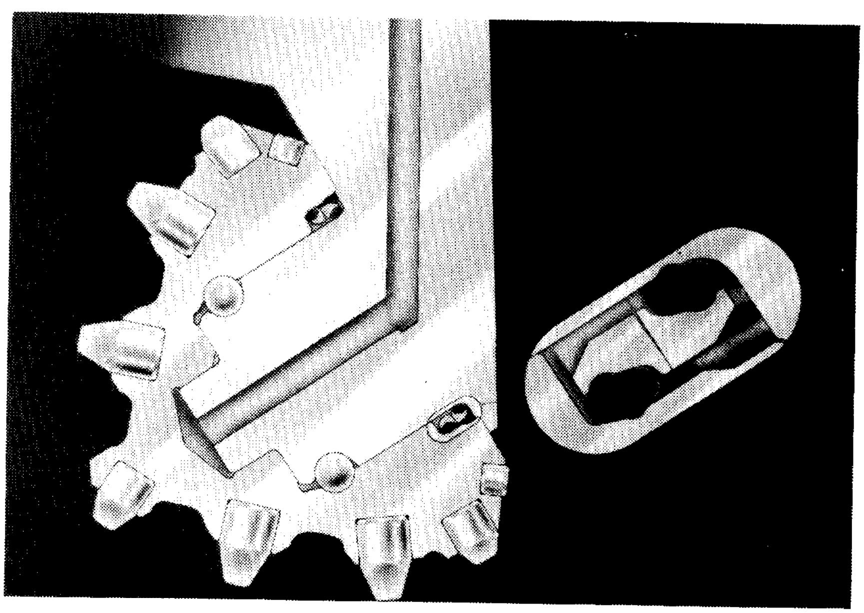

Figure 4 - Rock bit metal face seal

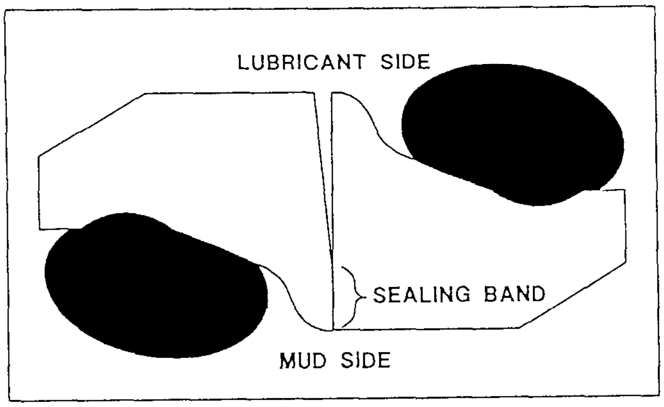

Figure 5a - Sealing band on new seal face

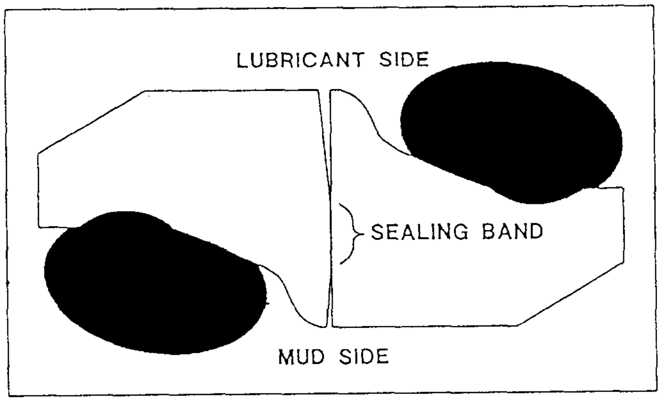

Figure 5b - Sealing band on worn seal face

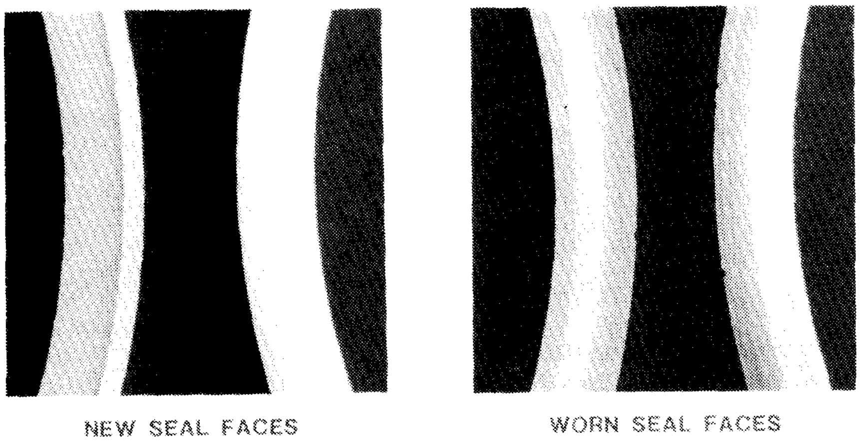

Figure 6

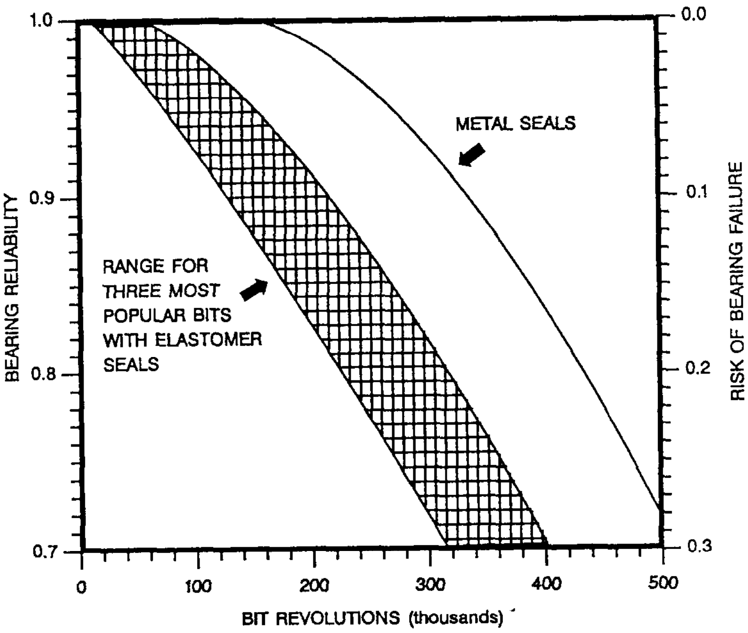

Figure 7 - Bearing reliability and risk of bearing failure for 8-3/4 inch IADC 537 bits used for horizontal drilling in the Williston Basin