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Bearing Wear Model for Roller Cone Bits

G. Hareland, SPE, and A. Wu, University of Calgary; J. James, SPE, Husky Energy

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Abstract

Bearing failure of roller cone bits may result in a time-consuming fishing job, and lead to significant increase in drilling costs. The bearing failure generally comes from over wear of frictional pairs (surfaces between the journal and bearing of the cone). A bearing wear model has been developed to predict the wear status through multi-variable nonlinear regression analysis based on field data. The wear model considers four variables including weight on bit (WOB), revolution per minute (RPM), diameter of bit and hours drilled as a function of IADC bit bearing wear. Some abnormal bit run field reported bearing failures were removed in order to acquire the best regression of the field data. A bearing failure probability model is then introduced to predict the survival probability of the bit, the parameter of which is obtained through statistics of more than 500 bit runs.

The wear status, including instantaneous and cumulative wear, for different roller cone bits and different wells drilled in Western Canada is simulated respectively with the wear model.

A good correlation coefficient was obtained for different IADC bit types including both milled tooth and insert roller cone bits. The cumulative wear values from the model match close those from the field.

The wear model and the failure probability model can help drilling engineers evaluate bearing wear status during real time drilling operations through simulation, and make a decision on when to pull out the bit in time to avoid bearing failures and the possibly lost cones. Better bearing wear predictability will result in better drilling results and effect the total drilling cost.

Introduction

Wear is very common in operation of mechanical products, especially to those with frictional pairs. There exist two main reported bit wears of rollercone bits during oil drilling operation with roller cone bits: cutting structure wear and bearing wear. Bearing failure wear should be paid more attention because bearing failure may in some cases produce catastrophic event whose consequences interrupt well progress and lead to significant remedial operations and costs.

The failure of a bearing is not necessarily the catastrophic event sometimes described. It takes typically several hours after the damage to the bearing for the cone to fall off. With the use of normalised down-hole mechanical parameters and simple logic, the torque created by the excess friction in the bearing and the torque caused by the locked cone dragging on the bottom of the hole can be differentiated from changes in lithology or drilling parametors (Lesage, M.L.G., 1988). Neural network have been successfully used in different fields due to their capability to identify complex relationship when sufficient data exist. A new model was successful in predicting the condition of the bit. Input: lithology, torque, ROP, WOB, RPM, HSI. Output: bit wear, including bearing wear and tooth wear (Bilgesu, H.I., 1997, 1988).

Some researchers have put forward emipricle formulae about bearing wear of roller cone bits since more than half century. The prediction of bearing wear is much more difficult than prediction of tooth wear. A bearing wear formula used to estimate bearing life is given by (Bourgoyne, 1991)

$$\frac{db}{dt}=\frac{1}{\tau_B}\left(\frac{v}{100}\right)^{b_1}\left(\frac{w}{4d}\right)^{b_2} \tag{Eq.1}$$

Insert breakage rather than tooth wear is the primary cutting structure concern at high mechanical horsepower 1evels. Field experimentation yields data on allowable WOB and RPM to avoid insert breakage. Below these WOB and RPM restrictions, insert wear is negligible, so the remaining unknown in WOB and RPM optimization is bearing life (Doiron, H.H., 1987). Journal bearing insert bit runs without excessive insert breakage or gauge wear typically fail due to seal/bearing wear. The factors affecting seal and bearing surface wear are numerous and complex. A well known wear equation was selected to characterize generalized wear in a journal bearing (Doiron, H.H., 1987)

$$V=\frac{cLx}{p} \tag{Eq.2}$$

When a critical volume of material has been removed, the bearing failure will occur. After modification, the fomula is changed to:

$$V=K\cdot WOB\cdot RPM\cdot Hours \tag{Eq.3}$$

The bearing wear is proportional the frictional work, which mainly depends on the travel distance and contact pressure between two surfaces of cone and journal. The travel distance and contact pressure are related to rotary speed of bit and weight on bit. The maximum contact pressure $p_{\max}$ can be calculated according to Hertzian contact theory.

$$p_{\max}=\left(\frac{1}{\pi(1-\mu^2)}\cdot\frac{W}{L}\cdot\frac{\frac{1}{R_j}-\frac{1}{R_c}}{\frac{1}{E_j}-\frac{1}{E_c}}\right)^{0.5} \tag{Eq.4}$$

Because R_j, R_c and L are proportional to D_b, the diameter of the bit, pmax can be expressed as (Kelly J.L. Jr, 1990):

$$p_{\max}\propto\frac{(WOB)^{0.5}}{D_b} \tag{Eq.5}$$

The bearing life parameter is given as:

$$l_b=60\cdot RPM\cdot T\cdot(WOB)^{0.5} \tag{Eq.6}$$

Bearing wear model

From the above it can be seen that the bearing wear of a roller cone bit is mainly related to the two important drilling parameters, WOB and RPM. In fact bearing wear is a complex process, concerning with many factors, such as bit type, formation, BHA, and down hole conditions. Therefore the two independent variables WOB and RPM are selected to model bearing wear.

In addition, the wear is related to bit diameter D_b as well as time which should be in the model. In order to make the model more flexible, each variable is assigned a power. A synthetic coefficient K is introduced, so the final model is assumed as follows:

$$Bw=K\cdot(D_b)^a\cdot T^b\cdot(WOB)^c\cdot(RPM)^d \tag{Eq.7}$$

If we know the depth drilled or H_{out}-H_{in}, and the interval of measureing is one meter, the instantaneous accumulative bearing wear is:

$$Bwa=Bw_0+K\cdot\sum_{i=1}^{H_{out}-H_{in}}\left(\left(\frac{1}{ROP_i}\right)^b\cdot(D_b)^a\cdot(WOB_i)^c\cdot(RPM_i)^d\right) \tag{Eq.8}$$

Field data collection

The data are obtained from a database of drilling parameters records, and a total number of 500 bit runs are extracted. These drilling data were measured in hundreds of western Canada wells.

Coefficients of bearing wear model

Among the 500 sets of bit runs only selective runs were used to do the regression analysis (**Figure 1**). According to some of the field data (**Table 1**), multiple variables nonlinear regression is applied. The analysis coefficients and coefficient of multiple determination are shown in **Table2**. When some of coeffecents are assigned fixed values, the model becomes other researchers' models (for examples by Kelly and Doiron).

From **Table2** it can be seen that the coefficient of multiple determination of both Kelly and Doiron model has a low value. However, this doesn't always mean the higher the value of coefficient of multiple determination, the better the final bearing model.

Application of bearing wear model

After the coefficients in the model are obtained, it can be used to predict the bearing wear under certain conditions (**Figure 2**, **Figure 3**, **Figure 4**, **Figure 5**, and **Figure 6**). The different models reported in the litherature to predict the bearing wear were compared to the results from the new model with field data.

Two groups of field data are used to verify the bearing models. **Table 3, Figure 7** and **Table 4, Figure 8** reflect the prediction results of different models respectively.

We find that the authors' model can make a better prediction than other models in calculating both the instantaneous and cumulative wear. Although the model without any assignment has the best prediction for cumulative wear, it couldn't be used to predict instantaneous wear. We also assigned different coefficients to form Bourgoyne's model, but couldn't get good results. Therefore each model has its own application conditions or application limits. The practicity of these empirical formulae mainly depends on the accuracy of original data. Through comparison of different models, the bearing wear model obtained by the authors of this paper has a better prediction than other models (**Table 5**). However it could be improved by using more and better drilling data. If possible the bearing model can be modified for roller cone bits with different IADC code, which means each IADC class has its own set of coefficients.

In addition, the model can be used to total hours if given other parameters. For example, assume that the used bits will continue to be used till totally worn out, then the left hours can be predicted. **Figure 9** can show clearly the additional hours (hatched parts)

$$T = \left(\frac{Bw}{K \cdot (D_b)^a \cdot (WOB)^c \cdot (RPM)^d} \right)^{\frac{1}{b}} \qquad \text{Eq.9}$$

The left hours can be used for drilling engineers to make decision on when to pull out the bits.

Bearing failure probability

The life of a roller cone bit bearing mainly depends on the seal, so if the seal fails the bearing will fail quickly. The survival probability of the bit bearing after L hours can be expressed as the following (Kelly, 1988):

$$P_s(L) = e^{-\int_0^L h dl} \qquad \text{Eq.10}$$

The failure probability is:

$$P_f(L) = 1 - P_s(L) \qquad \text{Eq.11}$$

Where

$$h = \frac{1}{Q} \cdot \frac{dF}{dl} \qquad \text{Eq.12}$$

We used the 500 bit runs to make statistical analysis for the bearing seal, and calculated the h of roller cone bits with different IADC codes. The analysis results are shown in **Table 6**.

Take an IADC517 bit as example, after the bit runs 30, 70, 120 hours respectively, its survival probability is:

$$P_s(30) = e^{-\int_0^L h dl} = e^{-30*0.003833} = 89.14\% ; \quad P_s(70) = 76.47\% ; \quad P_s(120) = 63.13\%$$

And its failure probability correspondingly is:

$$P_f(30) = 1 - P_s(30) = 1\text{-}89.14\% = 10.86\%; \quad P_f(70) = 23.53\%; \quad P_f(120) = 36.87\%$$

So, the survival or failure probability of a roller cone bit can also be used for drilling engineers to make decision on when to pull out the bits.

Conclusions

- A bearing wear model for roller cone bits has been developed to predict the wear status, including instantaneous and cumulative wear. The cumulative wear values from the model match those from the field. The model can also be used to predict the left hours of the used bit under certain conditions.

- A bearing failure probability model is introduced to predict the survival probability a certain amount of hours after a roller cone bit runs.

- The wear model and the failure probability model can help drilling engineers evaluate bearing wear status during real time drilling operations through simulation, and make a decision on when to pull out the bit in time to avoid bearing failures and the possibly lost cones.

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- The authors' model has a better prediction compared to other researchers'. The performance of the bearing wear models and bearing failure probability in this paper depends on the quality and quantity of the collected drilling data.

Acknowlegements

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Nomenclature

a =coefficient
b =fractional bearing life that has been consumed, Eq.1
b =coefficient, Eq.7
b_1 =bearing wear constant
b_2 =bearing wear constant
B_1 =bearing wear exponent
B_2 = bearing wear exponent
B_w =bearing dull grade, (0-8)
B_{wa} =instantaneous accumulative bearing dull grade (0-8)
B_{w0} =initial dull grade. if new bit, it is 0
c =coefficient, Eq.7
c =wear coefficient, Eq.2
c =coefficient of wear
d =coefficient
d_b =bit diameter, inches
D_b = bit diameter, inches
E_j, E_c=modulus of elasticity for journal and cone
F =number of bit with bearing failure
H_{in} =depth put in, m
H_{out}=depth pulled out,m
Hours=time
K =coefficient, obtained by regression according to the field data as shown in Table 1.
l =life parameter
L =load on sliding surface, Eq.1
L =length of the bearing, Eq.4
l_b = bearing life parameter
N =rotary speed, rpm
p =hardness of material
p_{max} = maximum contact pressure
p_f =failure probability
p_s =survival probability
Q =number of bit in service

R_j, R_c=radii for journal and cone
RPM = bit rotary speed, rpm
ROP_i=instantaneous ROP corresponding to drilled depth Hi
RPM_i=instantaneous RPM corresponding to drilled depth Hi
t =time, hours
T =Hours drilled
V =rotary speed, rpm, Eq.1
v =volume of seal/bearing , Eq.2
w =weight on bit
W = bit weight, 1000 lbf, Eq.1
W =force applied on the journal, close to 1/3 of WOB
WOB = weight on bit
WOB_i=instantaneous WOB corresponding to drilled depth Hi
x =distance traveled
μ =Poisson's ratio for the two materials
τ_B =bearing wear constant, hours

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Table 1 Selected bit runs for regression analysis

Size(mm)	Make	IADC	Depth out(m)	Distance drilled(m)	Hours	ROP(m/hr)	Weight(klb)	RPM	Pump press.(psi)	MUD WT(kg/m^3)	Bearing Dull
222	REED	447	2561	181	41	4.41	15.83	105.83	6861	1092	2
200	HUGHES C	117	1100	147	6	24.5	13.00	160.00	3079	1046	1
222	HUGHES	517	1435	416	91.75	4.53	13.11	75.83	6546	1066	4
222	HUGHES	537	1519	84	27.25	3.08	14.71	66.43	5041	1094	1
222	HUGHES	517	1058	694	76.75	9.04	12.00	86.39	4398	1010	4
222	HUGHES	517	1103	737	82.25	8.96	10.89	81.05	3542	1003	4
159	VAREL	517	1368	132	59.25	2.23	10.00	93.57	6198	1183	3
159	REED	437	1404	36	22.75	1.58	10.00	103.75	6075	1187	2
222	HUGHES	517	1180	484	64.25	7.53	10.67	80.00	3722	1008	4
200	SECURITY	537	2610	78	35.5	2.20	16.00	65.83	6448	1141	2
200	D.B.S.	537	2221	271	77	3.52	17.29	67.14	5532	1038	3
200	HUGHES/C	537	2345	59	16	3.69	14.33	75.00	7013	1065	1
222	REED	527	2081	163	23.5	6.94	13.13	61.88	5619	992	2
155.6	REED	537	3162	206	64.5	3.19	7.43	60.57	8575	1023	3
200	H.C.	517	1597	1099	80	13.74	14.67	99.17	4329	1054	4
349	RUSSIAN	117	129	129	4.25	30.35	4	142.67	4333	1211	1
311	SMITH		616	84	27.25	3.08	5.5	175	6437	1185	3
311	J & L		158	158	19.00	8.32	6.5	137.5	6000	1048	2
311	J & L		620	295	27.25	10.83	10.75	171.7	14799	1096	2
222	SMITH	517	1890	40	10.00	4.00	17.75	87.5	15810	995	1
251	KINGDREA	117	617	248	51.75	4.79	6.35	181.5	9865	1100	6
311	KINGDREA		169	151	15.00	10.07	6	130	6252	1042	2

Table 2 Coefficients in the models

	K	a	b	c	d	R^2
Assign b (Author's Model)	0.00073151	-0.20000	1.00000	0.15000	1.1158	0.76309
Assign a, b, c and d (Kelly model)	0.00017894	0.00000	1.00000	0.50000	1.00000	0.57886
Assign a, b, c and d (Doiron model)	4.91411E-5	0.00000	1.00000	1.00000	1.00000	0.18570

Table 3 Comparison of the field data to the estimated from the wear model

Size(mm)	Make	IADC	Depth out(m)	Distance drilled(m)	Hours	Weight(klb)	RPM	Bearing Dull	Estimation	Error
251	KINGDREA	117	617	248	51.75	6.35	181.5	6	5.01	16.50%
159	REED	437	1404	36	22.75	10.00	103.75	2	1.85	7.50%
222	HUGHES	517	1058	694	76.75	12.00	86.39	4	3.61	9.75%
222	HUGHES	517	1103	737	82.25	10.89	81.05	4	3.92	2.00%
222	HUGHES	517	1180	484	64.25	10.67	80.00	4	3.00	25.00%

200	H.C.	517	1597	1099	80	14.67	99.17	4	4.71	17.75%
222	HUGHES	517	1435	416	91.75	13.11	75.83	4	4.24	6.00%
222	HUGHES	537	1519	84	27.25	14.71	66.43	1	1.17	17.00%
200	HUGHES	617	1517	182	49.5	12.88	89.38	3	2.65	11.67%

Table 4 Comparison of the field data to the estimated from the wear models

Size(mm)	Depth out(m)	Hours	Weight(klb)	RPM	Bearing Dull	Author's Model	Kelly's Model	Doiron's Model
222	158	27	5.33	114.17	3	1.71858	1.26	0.81
222	240	72	9.90	79.00	5	3.315363	3.21	2.78
159	329	102.25	9.93	90.00	5	5.80386	5.19	4.49
311	428	31.25	11.00	161.25	3	3.019152	2.99	2.72
222	944	74.25	15.17	89.44	3	4.171956	4.63	4.95
311	324	42.25	10.00	179.00	3	4.521251	4.28	3.72
200	455	87.25	14.56	82.22	3	4.5291	4.90	5.13
200	182	49.5	12.88	89.38	3	2.769028	2.84	2.80
311	153	15.25	5.3	150	2	1.219155	0.95	0.60
222	387	12.00	5.5	142	1	0.969924	0.72	0.46

Table 5 Comparison of relative error of the wear models

	Relative Error		
	Author's Model	Kelly's Model	Doiron's Model
First Group	12.11%	18.89%	25.71%
Second Group	28.36%	34.37%	42.73%

Table6 Bearing Failure Statistic Results of Different IADC Roller Cone Bits

IADC	Total Number	Effective Seal	Failure Seal	0-8	Failure Percentage	Average Hours	h
114-227	21	8	1	12	11.11%	24.00	0.00462963
417	9	5	0	4	0.00%	0.00	
427	8	2	0	6	0.00%	0.00	
437	46	22	5	19	18.52%	50.40	0.003674309
447	51	31	1	19	3.13%	43.00	0.000726744
517	129	54	15	60	21.74%	56.71	0.003833386
527	57	32	10	15	23.81%	45.63	0.005217954
537	89	41	13	35	24.07%	44.00	0.00547138
547	1	1	0	0	0.00%	0.00	
547	16	8	3	5	27.27%	54.00	0.005050505
617	57	34	4	19	10.53%	42.88	0.002454831
627	12	7	1	4	12.50%	68.75	0.001818182
637	4	3	0	1	0.00%	0.00	

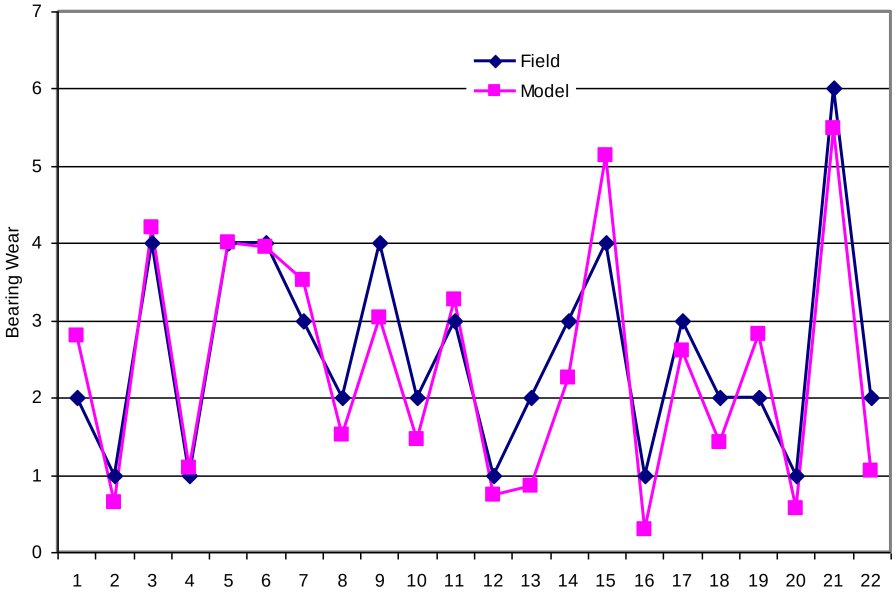
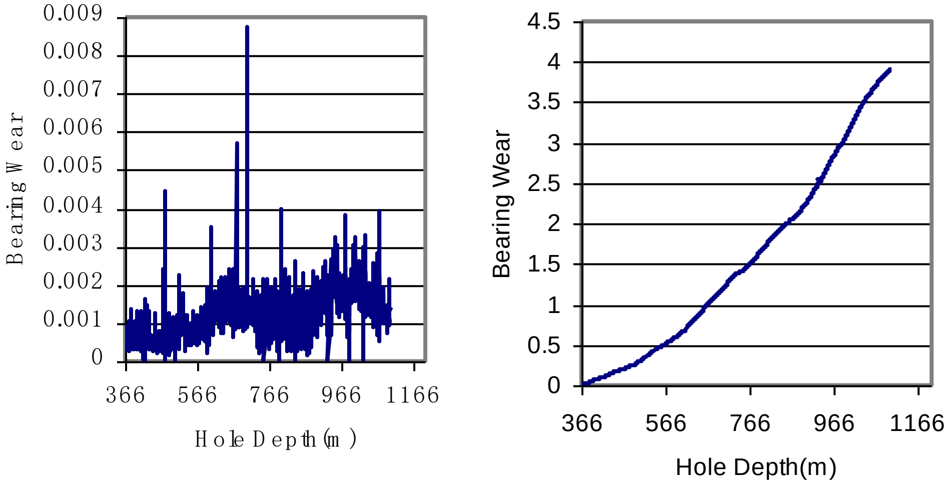
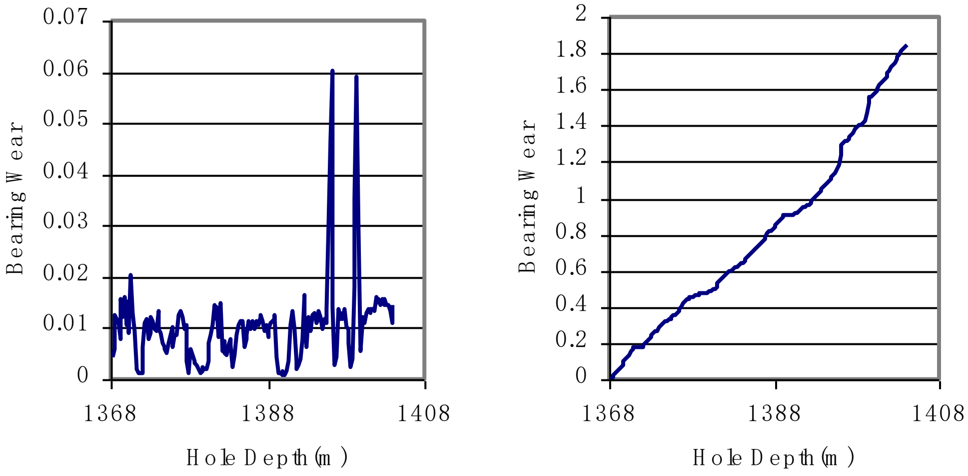


Figure1. Regression analysis results



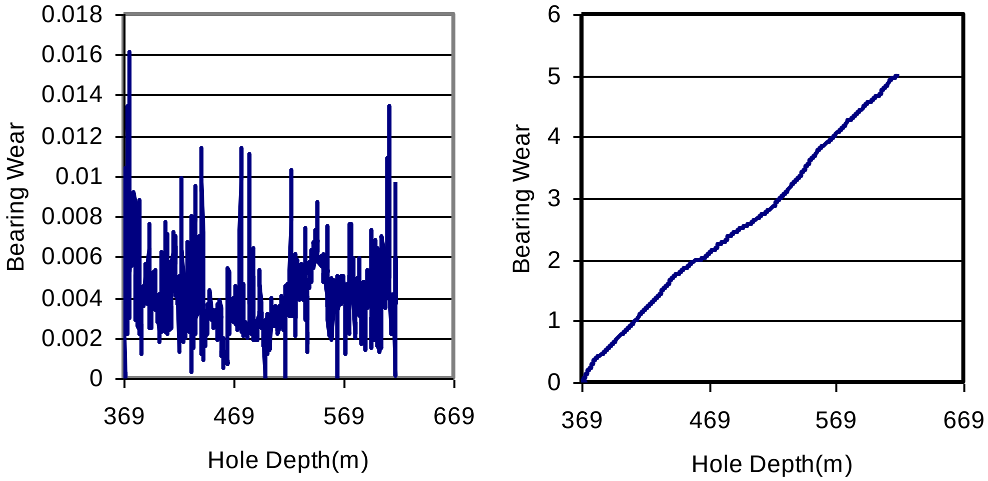
A: Instantaneous wear B: Cumulative wear

Figure 2 Wear estimation of Hughes 517 bit



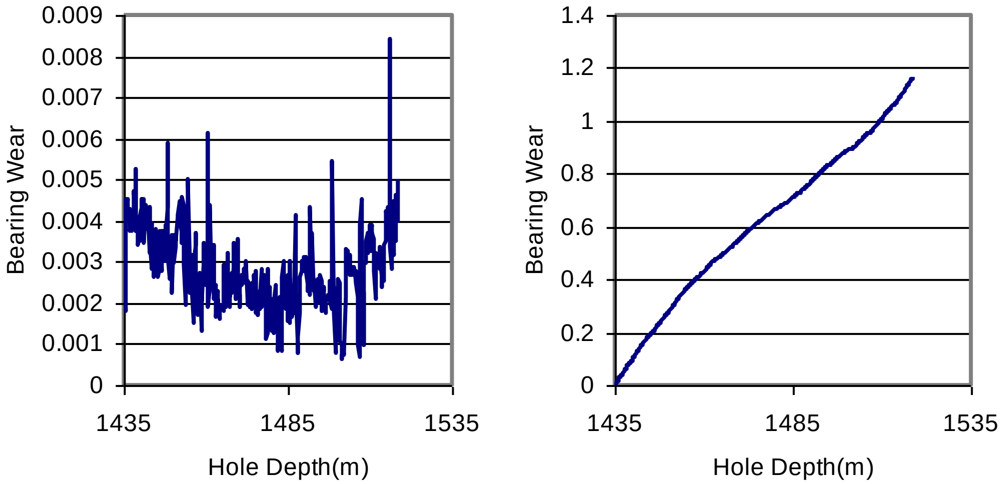
A: Instantaneous wear B: Cumulative wear

Figure 3 Wear estimation of Reed 437 bit



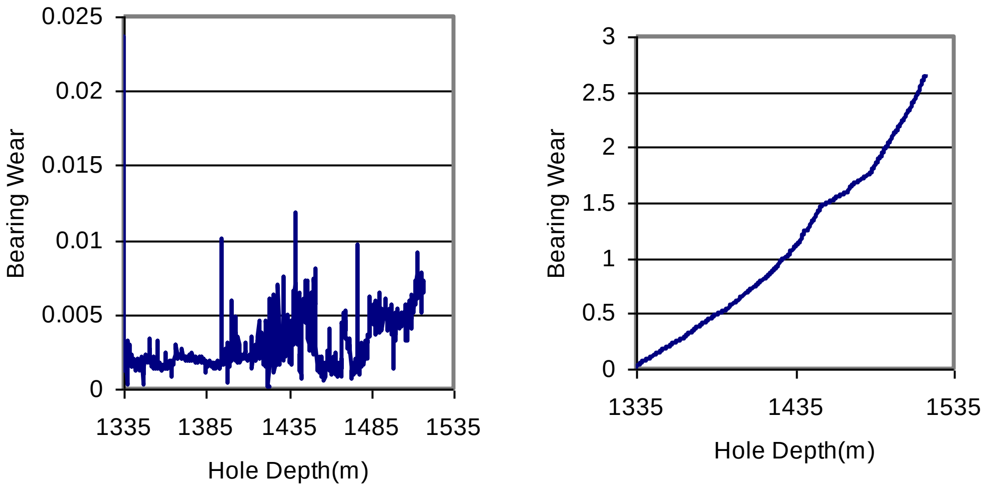
A: Instantaneous wear B: Cumulative wear

Figure 4 Wear estimation of Reed 117 bit



A: Instantaneous wear B: Cumulative wear

Figure 5 Wear estimation of Reed 537 bit



A: Instantaneous wear B: Accumulative wear

Figure 6 Wear estimation of Reed 617 bit

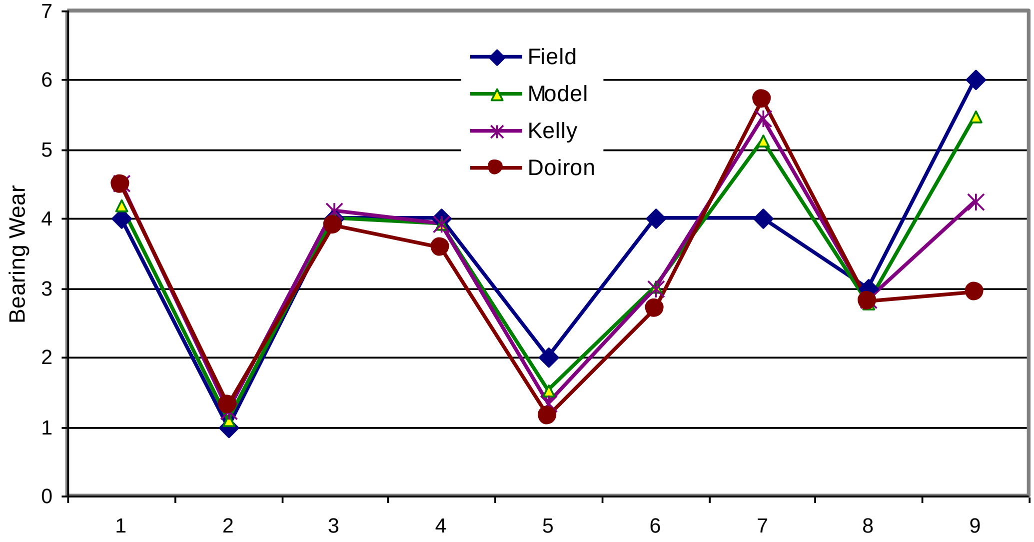


Figure 7 Comparison of field data to values from bearing wear models (First Group Data)

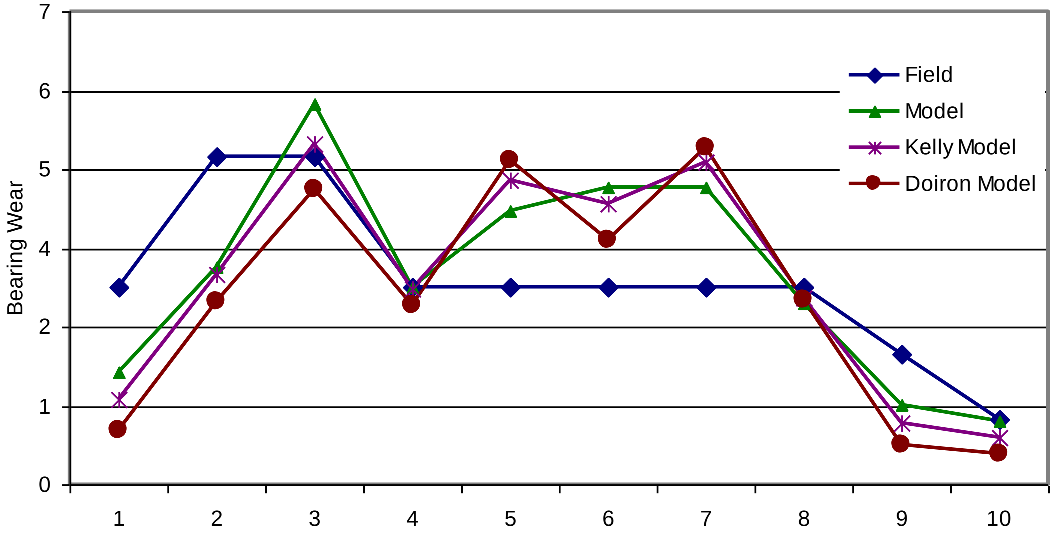


Figure 8. Comparison of field data to values from bearing wear models (Second Group Data)

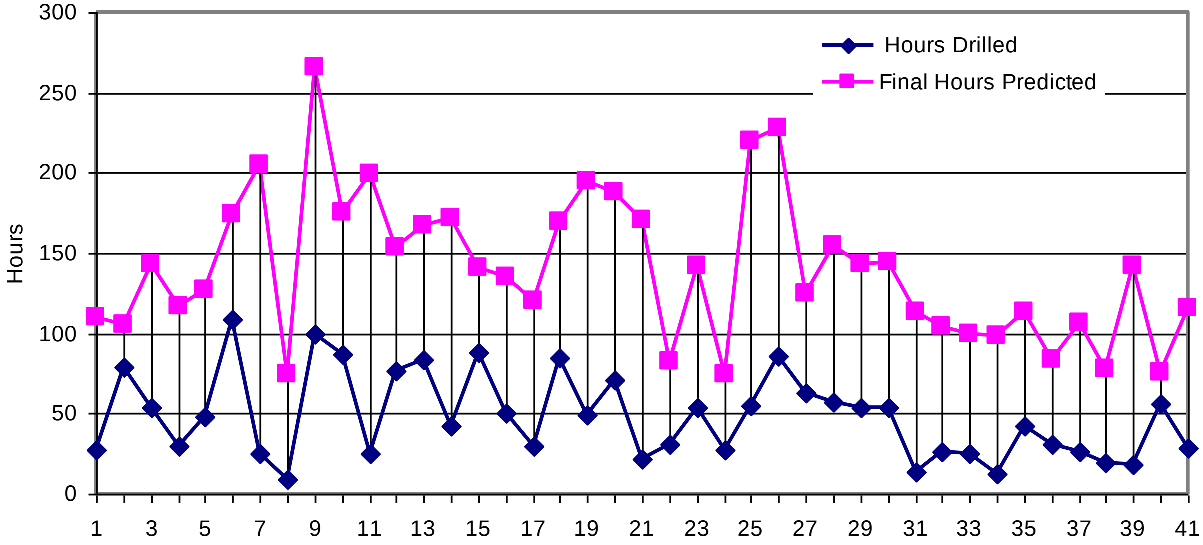


Figure 9 Left hours prediction of used roller cone bits