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用超声波检测信号预报抽油杆剩余寿命*

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摘要　目前研究抽油杆剩余寿命的理论方法没有一种可直接应用于现场,无法直接通过工程检测手段来判断抽油杆的剩余寿命。为此,通过抽油杆疲劳试验,找出裂纹前缘的变化规律,得出裂纹深度与裂纹面积之间的关系、裂纹面积与剩余寿命的关系,借用传统 Paris公式的数学模型,通过超声波检测建立了超声波探伤信号与裂纹深度之间的关系式,即裂纹检测信号与裂纹扩展规律之间的关系,从而提出了直接利用超声波探伤信号确定抽油杆剩余寿命的方法。将研究结果与疲劳模拟试验得出的剩余寿命相比较,寿命预测符合率达 84%以上。

关键词　超声波探伤　信号　裂纹深度　抽油杆　剩余寿命

中图分类号: TE933. 2　　**文献标识码**: A

抽油杆是油田应用最为广泛的采油部件之一,每年都有许多油井因抽油杆失效而造成井下事故,给油田带来了巨大损失。国内外对抽油杆进行了许多研究,但都未见到明显的事故下降或减少,分析其原因有二:首先在检测方法上过去一般都采用涡流探伤[1~2]、漏磁探伤[3~4]等手段,而这些方法无法检测到非常微小的疲劳裂纹及裂纹形状尺寸,使得大量的疲劳裂纹隐患隐藏在抽油杆中,最终造成井下事故;其次,过去对抽油杆疲劳裂纹的估算方法研究都与现场工程无损探伤手段严重脱离,其理论模型以裂纹深度为判断依据,而在实际工程应用中,裂纹深度是无法直接测量的。

实际上,无法直接通过常规无损探伤信号确定裂纹深度与长度的原因在于,通常的探伤信号只是一个当量值,从中无法同时提取关于裂纹深度和长度的信息。其解决方法为:以传统的 Paris公式为理论基础,通过对疲劳裂纹扩展规律的研究,将超声波无损检测手段应用于裂纹扩展实验,建立超声波无损检测信号与裂纹深度的关系,最终实现工程上判定裂纹尺寸与预报抽油杆疲劳寿命的目的。

1　剩余寿命计算模型

在现有的描述裂纹扩展速率的模型中, Paris公式是应用最为广泛的一个模型[5],其表达式为

$$\frac{\mathrm{d}a}{\mathrm{d}n} = C(\triangle K)^m \tag{1}$$

可得扩展寿命的表达式

$$n = \int_{a_0}^{a_c} \frac{\mathrm{d}a}{C(\triangle K)^m} \tag{2}$$

在计算寿命 n时,需要用到材料的疲劳裂纹扩展参数 C、m与应力强度因子表达式, C、m可以通过裂纹扩展实验确定。应力强度因子表达式采用大庆石油学院研究报告[6~7]给出的仅与裂纹深度有关的应力强度因子近似表达式

$$\triangle K_a = \triangle\sigma Y_a \sqrt{\pi a},\ \triangle K_s = \triangle\sigma Y_s \sqrt{\pi a} \tag{3}$$

$$Y_a = 1.09 + 0.062\frac{a}{r} - 0.479\frac{a}{c} + 0.339\frac{a}{r}\frac{a}{c} + 1.489\left(\frac{a}{r}\right)^3 - 0.646\left(\frac{a}{r}\right)^3\frac{a}{c} - 0.618\left(\frac{a}{r}\right)^2\left(\frac{a}{c}\right)^2 \tag{4}$$

$$Y_s = -0.271 + 1.669\frac{a}{r} + 2.163\frac{a}{c} - 1.466\left(\frac{a}{r}\right)^2 - 2.098\frac{a}{r}\frac{a}{c} - 1.235\left(\frac{a}{c}\right)^2 + 1.982\left(\frac{a}{r}\right)^3 + 1.278\frac{a}{r}\left(\frac{a}{c}\right)^2$$

$$0 < \frac{a}{r} < 1.2,\ 0.1 < \frac{a}{c} < 1.2 \tag{5}$$

式中, $\triangle K_a$为椭圆裂纹最深点应力强度因子幅值;

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△σ为杆体裂纹所在截面的应力幅值, Pa; r为杆体半径, mm; a、c为裂纹深度和宽度 (见图 1), mm; C、m为材料疲劳参数,通过裂纹扩展实验确定; Y_a、Y_s为椭圆形裂纹最深点和表面点的形状因子。

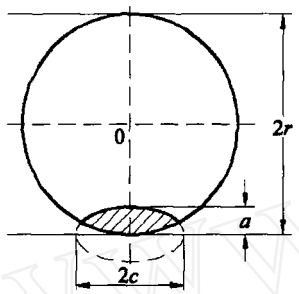

图 1 抽油杆疲劳裂纹典型形状

式 (4)、(5)中包含了 2个参量 a和 c,如果能够确定,则可求得剩余寿命。但是在工程中只能得到检测信号而无法得知裂纹深度,因此又研究了检测信号与裂纹深度之间的关系。

2 疲劳裂纹扩展参数确定

实验过程中采用降载法在断口上勾线,以前的研究成果中已经得出结论,圆棒试件上的疲劳裂纹可以用椭圆进行模拟。一般情况下,可以借助工具显微镜在多个点测量断口上裂纹扩展迹线深度,然后回归得到该椭圆的长、短半轴。本实验中采用了更为直观的办法,从上述试件断口中选择了勾线清晰、易于辨认边界的照片,利用图片处理软件对照片进行放大,沿着断口上留下的裂纹扩展迹线绘制椭圆 (如图 2所示),并记录描绘出的椭圆的长、短轴,计算出两者的比例。

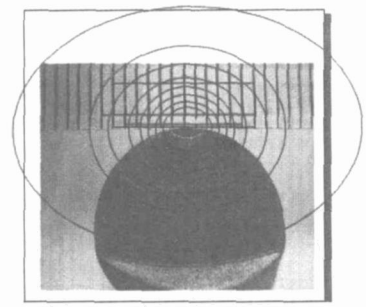

图 2 在断口上描绘的椭圆

在双对数坐标下结合 da/dn数据可以求得抽油杆材料的疲劳参数 C和 m。拟合结果见图 3。

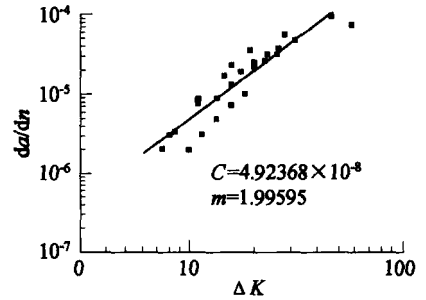

图 3 裂纹扩展速率实验参数拟合

3 裂纹深度与超声波探伤信号的关系

疲劳实验机上对圆棒试件进行有超声波探伤仪[4]监测的疲劳裂纹扩展实验,实验中采用降载勾线方法在试件断口上留下裂纹扩展迹线,实验结束后用工具显微镜测得扩展迹线之深度值;同时,随机选择若干时刻记录超声波检测信号幅值、以及超声波探头测量的裂纹信号,得到的数据 (见表 1)可以用于分析超声波信号与裂纹深度的关系。

表 1 试件超声波测量信号 V与裂纹深度 a的关系试验数据

试件 1		试件 2		试件 3		试件 4	
a/mm	V/mV	a/mm	V/mV	a/mm	V/mV	a/mm	V/mV
1.14	0.29	1.47	0.40	1.42	0.28	1.50	0.29
1.71	0.34	2.05	0.42	2.93	0.36	3.43	0.42
3.09	0.45	3.02	0.47	4.48	0.60	5.14	0.64
3.59	0.55	4.29	0.78	7.50	0.84	6.83	0.86
5.39	0.60	5.80	0.88			7.90	0.92
7.40	0.82						

由上述数据点的拟合结果可知,超声波检测信号幅值与裂纹深度大致成线性关系

$$V = 0.172 + 0.096a \quad (6)$$

4 确定抽油杆的剩余疲劳寿命

已经建立了裂纹深度 a与超声波检测信号 V的联系,在此基础上,能够通过超声波探伤信号判定裂纹深度,从而确定抽油杆剩余寿命。根据超声波信号 V估算试件载荷循环次数 n的结果与实验值对比情况见图 4,计算结果与实验值的误差见表 2。

从表 2可以看出,深度 1 mm左右的疲劳裂纹,在实验条件下,寿命大约是 72万次。在疲劳试验中

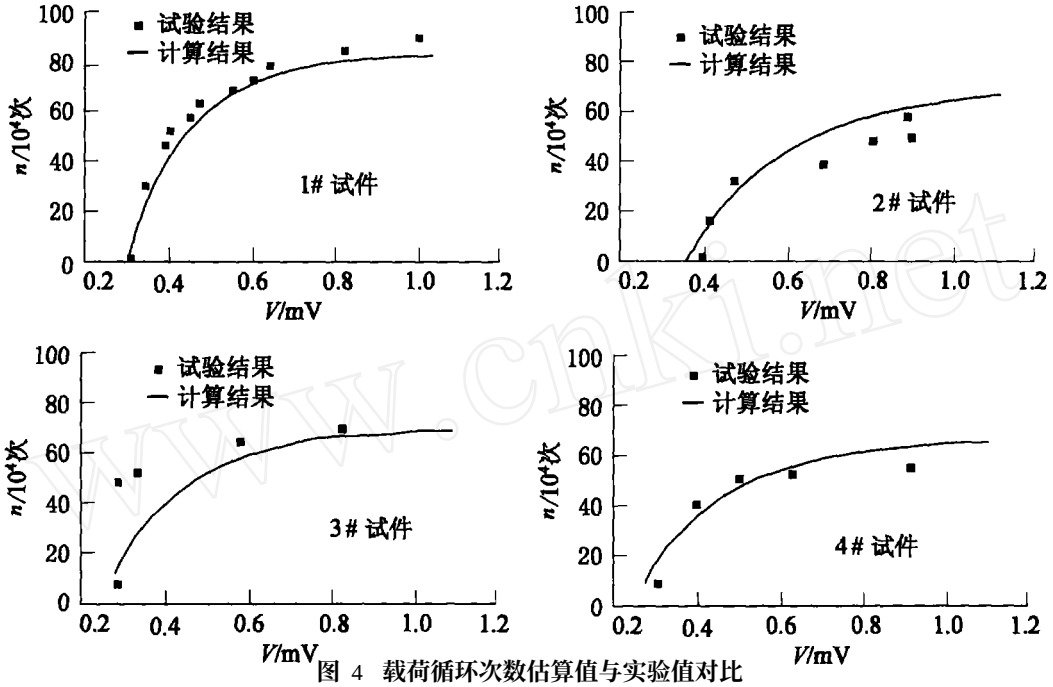

图 4 载荷循环次数估算值与实验值对比

表 2 试件寿命计算值与实验值误差

试件号	裂纹深度 /mm		n实验值		n计算值		误 差	
	初始值	最终值	疲劳次数 /10^4次	折算时间 /d	疲劳次数 /10^4次	折算时间 /d	相对误差 /%	折算时间 /d
1	1.14	5.39	72.0	125	69.9	121	2.9	4
2	1.47	5.8	61.4	106	51.6	90	16	16
3	1.42	7.8	64.0	111	65.5	114	-2.3	3
4	1.50	7.9	54.7	95	57.9	101	-5.9	6

注:折算时间按抽油杆工作冲次为 4次 /min时计算。

静拉应力和交变应力都是模拟抽油杆在井内的实际情况,但是应力的交变频率不同,如果抽油杆在工作中所受的交变应力为 4次 /min,每天的应力循环次数为 4938次,则 72万次的寿命相当于 125 d。

除 2号试件误差较大外,其它 3个试件的结果比较令人满意。误差原因在于在计算 $V-n$ 关系时,首先将探伤信号 V 转化为对应的 a,而 $V-a$ 关系目前根据实测结果近似直线拟合,2次近似将造成累计误差。同时,虽然直接从超声波检测信号判定抽油杆剩余寿命的过程中经过了 2次线性近似,但估算值与实验值的符合率仍然能够达到 84%。

5 结论

(1)建立了通过超声波探伤信号判别抽油杆剩余寿命的简化方法,经实验室模拟试验验证,寿命预测符合率达到 84%以上。

(2)将此研究成果与抽油杆识别技术相结合,形成抽油杆使用、检测、判废、跟踪管理等现代化管理体系,科学合理地使用油管抽油杆,可以及时退役过期的抽油杆,减少抽油杆断脱事故发生,形成科学、有序、规范的管理体系。

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nan Oilfield Company, Nanyang 473132, Henan), Duan Fumin, Shen Xiuli, Wang Xuehong

Abstract To solve the difference of polymer flooding in interlamination or in-layer, studied the technology of downhole separate injection of polymer solution, developed injection tool of low shearing, et al, and necessary running and pulling test instrument, realized downhole separate layer injection of polymer solution with single-string. Injecting polymer in 3 layers at the same time, and the drawdown reach 3.6 MPa at the flow rate of 180 m^3/d, the rate of shear degradation less than 6%, layered sealing pressure reached to 25 MPa, running and pulling loading smaller than 4 kN. Applications achieved effectively, and control the polymer solution flowing along high permeability reservoir in high speed, improve the development effect of polymer flooding.

Key words polymer flooding; low shearing; regulating separate layer injection; testing

STUDY OF VISCOSITY STABILIZER FOR POLYMER FLOODING

Wu Mingming, Zhao Xiutai, Qiu Guangmin (China University of Petroleum, DongYing 257061, Shandong), Zhang Guorong, Liu Gaoyou

Abstract The viscosity loss of polymer solution will affect the effect of the polymer flooding severely. bases on the characteristics and factors of polymer flooding, two kinds of stabilizers were designed, And evaluated its properties on improving and stabilizing of viscosity in laboratory, shows that the stabilizers not only improved the viscosity of the polymer solution but also stabilized the viscosity. When the concentration of stabilizers is between 800 and 1200 mg/L, the viscosity of polymer solution may be increased by two to five times and this can keeps stable more than 60 days. The rate of the viscosity loss of polymer solution is less than 15%. The stabilizers may be used in polymer flooding and depth profile control because they can compatibility well with the HPAM solution confected by tap water and brine.

Key words polymer flooding; viscosity; cross-linker; stabilizer

DETERMINATION OF PARAFFIN DEPOSITION AND RATIONAL THERMAL-WASH CIRCLE IN PRODUCER DURING POLYMER FLOODING

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Abstract For the serious problem of paraffin deposition during polymer flooding in Daqing Oilfield, analyzed the composition of produced crude oil and paraffin, and tested gas chromatogram of satisfied hydrocarbon, compared the results to water flooding, the content of saturated hydrocarbon in oil sample is lower, while the content of aromatic hydrocarbon and asphaltum is higher, but the difference is small; the content of saturated hydrocarbon and aromatic hydrocarbon in paraffin sample is apparently lower, while the content of asphaltum is much higher. Simulation experiment of dynamic pipe-flow shows that polyarylamide (PAM) has effect on inhibiting paraffin crystal forming and deposition. Analysis results of numerical simulation show that paraffin deposit rate is higher in producer during polymer flooding, generally, the paraffin deposit point is at about 400～600 m, and Rational thermal-wash circle should be less than 30 days.

Key words polymer flooding; pumping well; paraffin sample; thermal-wash circle

ANALYSIS ON POTENTIALITY OF INDIGENOUS MICROBIAL ENHANCEMENT OF OIL RECOVERY IN BLOCK 1 OF DAGANG KONGDIAN OILFIELD

Xiang Tingsheng, She Yuehui (Yangtze University, Jingzhou 434023, Hubei), N. T. Nazina, Feng Qingxian, Ni Fangtian

Abstract To investigate physical chemical condition, composition of microbial population, rates of sulfate reduction and methanogenesis in formation water of the block 1 of Kongdian Oilfield to study potential of microbial enhanced oil recovery. The amount of thermophilic aerobic saprotrophs, hydrocarbon-oxidizing bacteria, anaerobic fermentative bacteria, sulfate-reducing and methanogenic bacteria in injection and formation water were determined by most-probable-number (MPN) method. the sulfate reduction and the rate of methanogenesis processes were analyzed by radioisotopic method. The results show vary microflora inhabited in the block 1 of Kongdian Oilfield. The numbers of thermophilic aerobic saprotrophs and hydrocarbon-oxidizing bacteria in the injection water reached to 10^5 cells/mL and 10^3 cells/mL respectively. The population density of anaerobic fermentative bacteria in the injection water reached to 10^7 cells/mL, and sulfate-reducing bacteria reached to 10^2 cells/mL. Methanogenic bacteria were range from 1 to 10 cell/mL. Five kinds of bacteria above were also presented in production wells. So it is possible to enhance oil recovery by activating indigenous microbial of hydrocarbon oxidizing, fermentative bacteria and methanogenic bacteria in this area.

Key words Dagang Oilfield; indigenous microorganism; oil recovery

STUDY OF RECOVERY RATE OF HORIZONTAL WELLS IN SURPRESSURE, LOW-PERMEABILITY WITH BASAL WATER RESERVOIR

Qiu Ling (Research Institute of Petroleum Exploration and Development, Beijing 100083), Liang Jun, Li Yunjuan, Fan Zifei, Zhang Liqing, Ma Lili

Abstract In order to reasonably develop the unusual low-permeability and high pressure dual-porosity reservoir of Pre-salt carbonatite in Kenkiyak oil field, In this paper takes into account the factors such as pressure sensitization and bottom aquifer drive and studies the production characteristics of horizontal well and reasonable oil recovery rates by the numerical simulation of single well with dual-porosity model. The results show that the effective factors include the formation pressure, the energy of basal water, the pressure sensitivity and etc. In the natural depletion development, small bottom aquifer can improve recovery, and more sensitivity the stress of the reservoir is and less the degree of reserve recovery will be, and there is a maximum degree of reserve recovery in various producing rates. Therefore, account for recovery ratio, formation pressure and water cut, the proper oil recovery rate of Pre-salt carbonate reservoir of Kenkiyak field is 2%-3%.

Key words horizontal well; abnormal pressure; stress sensitivity; oil production rate; basal water

PREDICT REMAINING LIFETME OF PUMP ROD BY ULTRASONIC SIGNAL

Shi Huining, Yao Hongxing, Ding Jiandong (Huabei Oilfield Company, Renqiu 062552, Hebei), Meng Xianhong, Wang Rui, Chen Jinfang

Abstract No research theory of remaining lifetime of pump rod can be used to in-situ, and can not diagnose it remaining lifetime by engineering examine at present. From endurance testing of pump rod, fined change rules of leading edge of cracking, obtained relationship between depth and area of crack and relationship of crack area and remaining life, use Paris formula, established relation of ultrasonic inspection and crack depth, and relation of crack detection signal and crack spread law, proposed predict method of remaining lifetime of pump rod by ultrasonic inspection. Compared results of remaining lifetime by simulated test and theory predict, indicate it was coincide more than 84%.

Key words ultrasonic; fault detection; signal; crack depth; pump rod; remaining lifetime

INTEGRATED PRODUCTIVITY MODEL FOR GAS WELL WITH HIGH-PRESSURE GRAVEL-PACK SAND CONTROL

Dong Changyin (College of Petroleum Engineering, University of Petroleum, Dongying 257061, Shandong), Rao Peng, Feng Shengli, Zhang Qi

Abstract Productivity Ratio (PR) is firstly put forward to evaluate the effect of gravel-packing sand control measure on gas well productivity. After high-pressure gravel packing, there will form an additional flow resistance areas composed of gravel inside casing, perforation filled with gravel and the packed area outside the wellbore. Considering the non-Darcy flow, the pressure drop of radial and linear flow across the areas are calculated and the calculation method of PR is established. Combined with performance relationship (IPR) before sand control, the IPR curve after sand controlling could be obtained by PR. The application results indicate that this simplified model needs only fewer data but its results are very reliable.

Key words gas well; sand control; high-pressure gravel-pack; productivity prediction; IPR

CHEMICAL PLUGGING BOTTOM WATER TECHNOLOGY OF LENG41 BLOCK

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