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Research Article

The Horizontal Well Drilling Parameter Optimization Design Research

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Abstract: Extended-reach drilling technology has rapidly developed during the past three decades. It requires improved new models and technology. This study has created a rapid optimum method to design the horizontal well drilling parameters. Genetic Algorithm is applied in this method to optimize the parameters such WOB, RPM. According to practical situation, the suitable fitness function and value of operators of GA are given and reasonable convergence delay-independent conditions are set. Based on the intelligence and global quick search of GA and the convergence of GA, the design parameters can be globally optimized quickly and accurately. An example is taken to prove that the application of GA in the field of drilling parameters is successful. This optimization method based on GA can provide guide for field design.

Keywords: Drilling parameters, GA, horizontal well, nonlinear optimization

INTRODUCTION

In 1950s the scientific period took place with expansion in drilling research, better understanding of the hydraulic principles, significant improvements in bit technology, improved drilling fluid technology and most important of all optimized drilling. After 1970s rigs with full automation systems, closed-loop computer systems, with ability to control the drilling variables started to operate in oil and gas fields. The linear drilling rate of penetration model previously introduced by Bourgoyne and Yong (1974). In the mid 1980s operator companies developed techniques of drilling optimization in which their field personnel could perform optimization at the site referring to the graph templates and equations. In 1990s different drilling planning approaches were brought to surface to identify the best possible well construction performances (Bond *et al*., 1997). Later on "Drilling the Limit" optimization techniques were also introduced (Schreuder and Sharpe, 1999). Towards the end of the millennium real-time monitoring techniques started to take place, e.g., drilling parameters started to be monitored from off locations. Following the invent of the sophisticated and automated rig data acquisition microelectronic systems linked to computers, a range of drilling optimization and control services started to take place (Bradley, 1987). With advanced smart computer systems drilling penetration rate and bit lives are optimized with performing drill-off tests (Devereux, 1998). Currently state-of-the-art, high-speed IP communication systems are developed functioning with microwave broadband network, useful tool for oil and gas operations, enabling deployment of faster, more efficient networks to the fields (Nagel, 2009).

Genetic Algorithm (GA, genetic algorithm) is a kind of efficient parallel global search method to solve problem (Rabinovich and Wigderson, 1991), which reference Darwinian survival of the fittest, the survival of the fittest biological genetic mechanism and evolution, choose the operator, crossover operator and mutation operator role in groups, gained through iterative calculation problem of the optimal solution or approximate optimal solution. Genetic algorithm has simple calculation, weak dependence to the problem (such as does not require objective function continuous and differentiable, unimodal characteristics), easy to find the global optimal solution of the characteristics. Due to genetic algorithm of whole search strategies and optimization calculation does not depend on gradient information, has the very good robustness and so in the treatment of highly complex nonlinear problems, shows incomparable superiority. This study intends to use genetic algorithm parameters of PDC bit drilling multi-objective optimization.

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The objective of optimizing drilling parameters is to arrive to a methodology that considers past drilling data and predicts drilling trend advising optimum drilling parameters in order to save drilling costs and reduce the probability of encountering problems.

DRILLING PARAMETER OPTIMIZATION MODEL

Objective function: Rate of penetrate equation and wear equation are the base of bit drilling parameters multi-objective optimization. The rate of penetrate equation of this research is:

$$R = K(W - M_0)N^{\lambda} \frac{1}{1+C_1 h_f} \tag{1}$$

where,

- R = Rate of penetrate, m/h
- K = Formation drill ability coefficient
- W = Optimized WOB, kN
- M_0 = Zero water power thresholds WOB, kN
- N = To be optimized rotary speed, rpm
- λ = Rotary speed index
- C_1 = Tooth wear factors
- h_f = Tooth wear quantity

Hypothesis bit damage is mainly in the form of bit wear, then according to bit life equation and linear cumulative damage theory, can get a certain interval or a micro interval (according to formation parameter invariant principle, all well sections are divided into multiple intervals or some micro intervals) bit wear equation is:

$$\Delta h_f = \frac{\Delta t}{a\Phi^b W^c e^{dN}} \tag{2}$$

where,

- Δt = Bit drilling time, h
- Δh_f = Bit wears change
- a, b, c , d = Bit life equation coefficient
- Φ = Internal friction angle of rock,°
- W = Optimized WOB, kN
- N = To be optimized rotary speed, rpm

When Δt → 0, Δh_f → 0, Eq. (2) can be written as:

$$\frac{dh_f}{dt} = \frac{1}{a\Phi^b W^c e^{dN}} \tag{3}$$

Thus can get:

$$dt = a\Phi^b W^c e^{dN} dh_f \tag{4}$$

According to bit rate of penetrate and drilling footage H, relationship of bit working time t, Eq. (1) can be written as:

$$R = \frac{dH}{dt} = K(W - M_0)N^{\lambda} \frac{1}{1+C_1 h_f} \tag{5}$$

Then can get:

$$dH = K(W - M_0)N^{\lambda} \frac{1}{1+C_1 h_f} dt \tag{6}$$

Take Eq. (4) into Eq. (6):

$$dH = K(W - M_0)N^{\lambda} a\Phi^b W^c e^{dN} \frac{1}{1+C_1 h_f} dh_f \tag{7}$$

Integrate Eq. (7), H_f is bit total footage, hf_1, h_{f2} are initial wear and final wear of bit tooth:

$$\int_0^{H_f} dH = K(W - M_0)N^{\lambda} a\Phi^b W^c e^{dN} \int_{h_{f_1}}^{h_{f_2}} \frac{1}{1+C_1 h_f} dh_f \tag{8}$$

$$H_f = K(W - M_0)N^{\lambda} a\Phi^b W^c e^{dN} \frac{\ln \frac{1+C_1 h_{f_2}}{1+C_1 h_{f_1}}}{C_1} \tag{9}$$

Integrate Eq. (4), t_f is bit total drilling time, then:

$$\int_0^{t_f} dt = \int_{h_{f_1}}^{h_{f_2}} a\Phi^b W^c e^{dN} dh_f \tag{10}$$

$$t_f = a\Phi^b W^c e^{dN} (h_{f_2} - h_{f_1}) \tag{11}$$

The interval average mechanical rate of penetrate V is:

$$V = \frac{H_f}{t_f} = K(W - M_0)N^{\lambda} \frac{\ln \frac{1+C_1 h_{f_2}}{1+C_1 h_{f_1}}}{C_1 (h_{f_2} - h_{f_1})} \tag{12}$$

The drilling cost per meter C_{pm} is:

$$C_{pm} = \frac{C_b + C_r (t_f + t_t)}{H_f} \tag{13}$$

where,

- C_b = Drilling cost, RMB/unit
- C_r = Rig operating cost, RMB/hour
- t_t = Tripping, making a connection time, hour

Take Eq. (9), (11) to Eq. (13) can get the optimization objective function:

$$C_{pm} = \frac{C_1 C_b + C_1 C_r \left[a\Phi^b W^c e^{dN} (h_{f_2} - h_{f_1}) + t_t \right]}{K(W - M_0)N^{\lambda} a\Phi^b W^c e^{dN} \ln \frac{1+C_1 h_{f_2}}{1+C_1 h_{f_1}}} \tag{14}$$

GENETIC ALGORITHM IN THE APPLICATION OF DRILLING PARAMETER OPTIMIZATION

Genetic algorithm of drilling parameter optimization: According to bit drilling parameter optimization solution characteristics of the model, from the solution speed, convergence characteristics into consideration respectively, basic genetic algorithm were improved.

- **Selecting adaptive crossover probability and mutation probability:** Crossover operator and mutation operator is one of the important factors to influence performance of genetic algorithm. In the iterative evolution process, should according to the fitness value changes, adaptively select crossover probability P_c and mutation probability P_m. For multimodal function optimization, GA has two kinds of performance: the first kind of performance is containing in the optimal solution of the area, GA has the ability to convergent to the optimal solution (local or global), this attributed to GA has selection operation; The second kind of performance is a pioneering solution new search space ability, this benefits from GA has the crossover and mutation operation. GA the two performances are sometimes contradictory, one is convergence and one is development. In the evolution of different groups, both requirements and rely on is different. In the local optimal solution place, hope to have great capacity to explore and little convergence ability, this can make the group jump out of local optimal solution trap. In the global optimal solution in the neighborhood for convergence capability is strong, without the need to develop ability, because the ability to develop will damage the global optimal solution. And these two kinds of performance of GA are dominant by the size of P_c and P_m. Adaptive selection and calculation formulas are:

$$P_c = \begin{cases} k_1(f_{\max} - f^{'})/(f_{\max} - f_{aveg}) & f^{'} > f_{aveg} \\ k_2 & f^{'} \le f_{aveg} \end{cases} \tag{15}$$

$$P_m = \begin{cases} k_3(f_{\max} - f)/(f_{\max} - f_{aveg}) & f > f_{aveg} \\ k_4 & f \le f_{aveg} \end{cases} \tag{16}$$

- **The optimal individual reserve:** A study suggests that the convergence for, in many cases, implement optimal individual reserve is the necessary premise to guarantee. The concrete practice is to get the optimal generation 0 of the individual (fitness value of the largest individual) and its fitness value keep up, from the first generation start, each generation to get the optimal individual and the first generation of keep individual carries on the comparison, if just get the best individual is better than the previous generation keep individual, then it will become the current generation of reserved individuals, otherwise will former generation keep individual as the current individual reserves. The reserves and individual fitness value can use variable separate save.

Table 1: Nanhai gas drilling parameter optimization results

Section (m)	WOB (Kn)	RPM (rpm)
0~400 (vertical section)	100	120
400~1600 (vertical section)	60	150
1600~2300 (vertical section)	80	120
2300~3200 (vertical section)	100	70
3200~3600 (buildup section)	100	60
3600~4800 (horizontal section)	150	Compound 30

Nanhai gas drilling parameter optimization results: Apply drilling parameter optimization model and genetic optimization algorithm established in this research, according to the field of real drilling data; the recommend bit drilling parameters are optimized. Optimization results are shown Table 1.

CONCLUSION

Take the gas lift efficiency as the optimum object, uses the Optimal Containment Genetic Algorithm (OMSGA) method to optimize the gas lift parameters and the approach is characterized by global optimization and quick search. This method can get the optimum results quickly and efficiently. So this method has certain guiding function to the draft of oil production plan.

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